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GENERAL SCIENCE

FOR COLONIAL SCHOOLS

BY
F. DANIEL, B.Sc.

Colonial Education Service

BOOK I

OXFORD UNIVERSITY PRESS

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PREFACE

This course of 'General Science' is the result of fifteen years of trial and experiment in two tropical parts of the British Empire. Its first aim is to teach science on a broad basis, as a part of the equipment of the average secondary school pupil for everyday life in a scientific age. I have tried to provide a Course which, although it is 'general' in touching everyday life at many points, is still 'science' in that it emphasizes fundamental principles. While the Course is primarily intended for that great majority of secondary school pupils whose schooling stops at the School Certificate stage, it will benefit others who intend to specialize in some corner of the scientific field, by giving an earlier survey of the whole of it.

During the last ten years, every lesson of the Course has been tried out thoroughly with several thousands of pupils (mainly Chinese, Indians, and Malays) in six different Malayan secondary schools. It has been taught by a dozen science teachers of different races, qualifications and experience; and although the books range over almost the whole field of pure science, the keen teacher who has specialized in one branch of science has proved that he can easily teach himself sufficient of the other branches to handle the Course effectively.¹

The Course is intended to occupy twenty-four year-periods, and it is recommended that this time-allowance should be allotted as follows: First Year, 5 three-quarter hour periods weekly; Second Year, 5 periods; Third Year, 7 periods; Fourth Year, 7 periods. Some classes have actually completed the Course in only twenty year-periods, but the rate of progress depends largely on the standard of English attained by the pupils. The present division into four one-year

¹ An account of the early stages of this experiment appeared in *Oversea Education* for Oct. 1936, Vol. VIII, No. 1, pp. 1-13.

parts is that which has proved most suited to the mental outlook and everyday experience of Malayan pupils. After passing through several editions in its earlier, duplicated, loose-leaf form, the Course is now published in book form in the hope that it may also be of use to secondary schools in other tropical and sub-tropical areas.

A special feature of the Course is the very careful attention that has been devoted to language simplification by eliminating non-essential technical words and relating the text to the standard vocabulary of 2,000 words adopted by the Oxford University Press as the basis for colonial school books. This removes one of the main reasons for the pupil's reliance on mere memory—the lowest of the human mental functions—for once he *understands* the ideas involved he can express them in his own words instead of using imposing technical tags as a substitute for real knowledge: merely 'labelling his ignorance'. In order to help the pupil in reading the text and building up his scientific vocabulary, the first occurrence of new words not in the standard vocabulary is marked either by an asterisk or by a dagger. The asterisk refers him to the glossary, where general words are simply defined. The dagger reference enables the pupil, by consulting the list of technical terms whenever necessary, to remind himself of their nature or meaning.

In the biological portions of the Course, the physiological approach has been followed throughout, and plant and animal types which are of very wide distribution have been selected with a view to making the Course suitable for use in most tropical and sub-tropical areas. The individual teacher, of course, can always supply additional 'local colour'.

The practical work involves only the simplest equipment and the cheapest materials consistent with worth-while results in the laboratory.

One of the main utilitarian aims of the Course is to provide a background for effective education in health, and since Hygiene (an applied science) can be little more than rule-of-thumb without a proper scientific basis, it is clearly desirable to teach it as a part of a general science

course. A book of Elementary Tropical Hygiene will be published as an adjunct to Book III of this series.

My thanks are due to all those who have helped me in any way with this educational experiment. To my friend and colleague, Mr. E. H. Bromley, for his many years of conscientious trial and experiment with this Course and for all his suggestions and constructive criticism. To my old pupil, Leong Pak Cheong, who has drawn most of the diagrams from my black-board diagrams and rough sketches. To Cheong San Thau and those senior boys of the Victoria Institution who have helped in working out the biological types, and also to Too Chee Choo, Keshmahinder Singh and A. Krishnappah for their continued interest and help after leaving school. To my assistants, Ahmad bin Haji Osman and Mohamed Basir bin Haji Abdullah, whose patience, skill and industry made it possible to produce the 10,000 loose-leaf text-books needed to carry out the experimental stages of the course on such a large scale. To the Malayan Government for permission to publish the course.

I am also grateful to Professor R. Douglas Laurie and to his Senior Lecturer, Dr. E. E. Watkin, for all their help, guidance and encouragement during my two periods of 'study-leave' in the Zoology Department at Aberystwyth in 1933-4 and 1937-8. To Professor V. H. Mottram (London), Professor H. Munro Fox, F.R.S. (Birmingham), Mr. T. L. Green (Bristol University) and Mr. G. N. Ridley (Wallasey Grammar School), who have given me many new ideas connected with various aspects of animal physiology. To the Board of Education Inspectors and the heads of secondary, central and elementary schools, for all the trouble they have taken to show me new developments in school science teaching during my visits to schools in England and Wales whilst on leave. To my friends in the Malayan Medical and Agricultural Services for giving me the benefit of their local knowledge. To Dr. L. Faucett and Mr. E. C. Parnwell for advice and encouragement in my problem of language-simplification. And especially to my friends, Messrs. W. G. Greaves and J. A. Lauwerys for reading

through the manuscript and for many helpful suggestions concerning 'General Science', a subject on which they are recognized authorities.

My thanks are also due for permission to reproduce diagrams from the following books: J. G. Frewin, *A New Experimental Science*, Part I, Fig. 9; E. J. G. Kirkwood, *Plant and Flower Forms* (Sidgwick and Jackson), Fig. 23; also Bishop and Locket, *An Elementary Chemistry*, Figs. 12, 58; Hart, *An Introduction to Physical Science*, Figs. 66, 70, 74; Hatfield, *An Introduction to Biology*, Figs. 25, 26, 31; Irvine, *West African Botany*, Figs. 27, 33, 37, 38, 39, 40, 41, 44, 45, 46, 47, 48, 49, 51; Skene, *School Botany*, Figs. 20, 30, 32, 40; Smith, *Experimental Biology*, Figs. 29, 50; all published by the Oxford University Press.

F. DANIEL

Kuala Lumpur

July 1940

INTRODUCTION

WHAT THIS SCIENCE COURSE IS ABOUT

When you see something that you have never seen before, your first thought is, 'What is it?' Then you ask yourself, 'What does it do?' Later on, if you have the right sort of inquiring mind, you will want to know, 'Why does it do this?' and perhaps, 'How does it work?'

One of the main objects of this 'General Science' Course is to provide the answer to questions such as these, and thus to explain to you the world in which you live.

You will realize at once that 'General Science' is going to be a very wide subject. We shall begin our work by grouping together all the things which are related to one another, and then study them in groups.

First of all, therefore, we shall draw a clear dividing line between those things which are *alive* and those which are *not alive*; that is, we shall classify all the things in the world into two main classes:

- (a) *The Living Things*, and
- (b) *The Non-Living Things*.

LIVING THINGS—PLANTS AND ANIMALS

When we speak of *living things* we probably think at once of things that move; but later on in this Science Course we shall meet some living things which remain still for quite a long time, while we have all seen many non-living things moving, e.g. a piece of paper blown by the wind, a stone thrown from the hand, a sailing-boat driven by the wind, a railway train drawn by an engine. We shall find, however, that a living thing *moves of itself*, while a non-living thing moves because it is pulled or pushed by something outside itself—by some outside force. All living things, too,

need *food* and *water*, part of which they use to build up their bodies—so that *growth* takes place. We shall also find that all living things *breathe*; and, most remarkable of all, they can produce young ones and so *reproduce* themselves.

The chief ways in which living things are different from non-living things, therefore, are

- (i) *Living things breathe, feed, and grow* (non-living things do not);
- (ii) *Living things can move of themselves, and can reproduce themselves* (non-living things cannot).

Living things, again, are divided into two main classes: (a) *Plants*, and (b) *Animals*.

You may think that you could decide at once whether any particular living thing you saw was a plant or an animal, but you will find that this is not always as easy as you think, until you learn the really important differences between these two classes of living things.

NON-LIVING THINGS—AIR, WATER, EARTH

Before we can study living things properly, we must find out something about the non-living part of the world which surrounds plants and animals, without which they cannot live. These non-living things may be put under the three headings: (i) *Air*, (ii) *Water*, and (iii) *Earth*.

You will learn later how green plants make use of simple, non-living things from each of these three sources—air, water, and earth—and change them into more complicated material; and how animals, in their turn, make use of the living material built up by plants.

Now we have a little clearer idea of what this ‘General Science’ Course is about. We are going to find the answers to a lot of questions about the things of everyday life—about non-living things; mainly air, water, and earth; and about living things: plants and animals. The questions are these: ‘What is it?’ ‘What does it do?’ ‘Why does it do this?’ ‘How does it do this?’

Note.—Before studying Chapter I read Appendix I and learn the names of Science Apparatus in Appendix II. Appendix III gives directions for weighing.

† Refers from the List of Technical Terms. * Refers to the Glossary.

CHAPTER I

THE AIR

WHAT IS AIR ?

Our first step in science is to find out something about one of the commonest things in the world—the air around us. We have become so used to being surrounded by air which we cannot see, or taste, or feel, that we often forget that it is there at all. We notice the air, however, when we move quickly through it while running, cycling, or motoring; or when the air moves past us, as when the wind blows. Yet it is rather difficult to realize that air is a material substance, just as earth or water is. We can have a ton of earth or a pint of water. Can we have a pint of air or a ton of air ? That is, does air occupy space, or take up room, and has it weight ?

DOES AIR OCCUPY SPACE ?

If an ‘empty’ beaker† or an ‘empty’ bottle is held mouth-downwards in water, no water enters it. This shows that there is some *material* inside the beaker or the bottle keeping the water out, i.e. *air occupies* space*.

If an ‘empty’ bottle is now held mouth-upwards under water, bubbles* of air escape from the bottle as the water enters, because *air occupies space* and the water cannot get in until the air gets out.

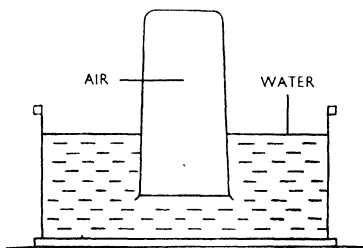


FIG. 1. AIR OCCUPIES SPACE

If the bottle is filled with water and is then held mouth-downwards in air, bubbles of air enter as the water leaves the bottle, the air taking up the room formerly occupied by the water.

These simple experiments show clearly that *air occupies space*. What we usually call an 'empty' pint bottle really contains a pint of air, and when we fill the bottle with water from the tap this pint of air has to get out before we can put a pint of water in. Hence it is quite reasonable to speak of pints or gallons or cubic centimetres or cubic feet of air.

DOES AIR POSSESS WEIGHT ?

Is it reasonable to speak of a pound of air, or of a ton of air ? To answer this question we must find out whether we can actually *weigh* some air. To do this we must drive out the air from a suitable vessel, weigh the vessel, let in the air once more, and then

weigh it again to see if there is any gain in weight. One way of doing this is as follows:—A round-bottomed glass flask† is fitted with a well-fitting rubber cork through which passes a short glass tube ending in a piece of rubber tube which can be closed with a screw-clip,* as shown in the diagram.* A little water is put in the flask, the cork is replaced (with the screw-clip *open*), and the water is boiled over a small Bunsen flame. When the water has been boiling for several minutes and the flask is quite full of steam (i.e. all the air has been driven out), the burner is removed and the screw-clip is closed as quickly as

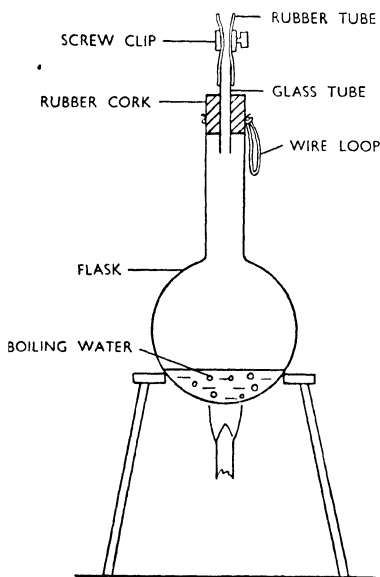


FIG. 2. AIR HAS WEIGHT

possible. The flask is allowed to cool and is then weighed, hanging from the hook of the balance by a loop* of wire. After the weight of the flask has been written down, the screw-clip is opened and we hear a hissing sound as the air rushes in. The flask is again weighed, full of air.

Weight of flask *before* opening clip = gm.

Weight of flask *after* opening clip = gm.

Therefore, weight of air in flask = gm.

It is clear that there is a distinct* *gain in weight*, hence the experiment shows that *air has weight*.

Hence, **air is a substance which occupies space and which has weight.** Every material substance known to Man has these two properties.

This air, of which we now know the weight, fills the space between the surface of the water in the flask and the cork. If we fill up the flask with water from a measuring-cylinder,* we can find the *volume* of the air that entered the flask when the screw-clip was opened.

Volume of air in flask = c.cm., hence c.cm. of air weigh gm.

Therefore, 1 litre† (1,000 c.cm.) of air weighs gm.

More careful and more accurate* experiments show that a litre of air weighs 1·3 gm., and a cubic foot of air weighs 0·08 lb.

Work out the weight of the air in a room which is 50 ft. long, 40 ft. wide, and 14 ft. high and write the answer here.

THE CHEMICAL NATURE OF AIR

THE AIR AND BURNING

Everyday experience teaches us (a) that when a fire is burning low, it can be made to burn up by blowing or fanning; (b) that it is very difficult for the firemen to save a burning building when a strong wind is blowing; (c) that oil lamps have air-holes at the top and also at the bottom, just below the flame. These everyday

examples show that the way in which a fire burns depends upon the supply of air. To find out what really happens when things burn in air, we shall now study a convenient kind of fire—a candle* flame.

TO FIND WHAT HAPPENS WHEN A CANDLE BURNS IN AIR

Light a short piece of candle and, when it is burning steadily, invert* a clean, dry gas-jar over it.

What happens ?.....
Raise the jar slightly so that you can take out the candle. Light it again and, when it is burning steadily, invert the same jar over it once more, being careful while doing so not to disturb the air inside the jar.

What happens ?.....
Why did the candle go out ? And why will the air which is left there *not* allow a candle to burn in it ? Perhaps something in the air has been used up by the flame ? But our simple experiment does not tell us that. To find if it is so, we must improve on our experiment and *measure* the volume of the air in the jar, before and after burning a candle in it. To do this, we shall invert a jar of air so that its mouth dips under water. Then, if a part of the air is used up by the burning candle, the water will rise in the jar.

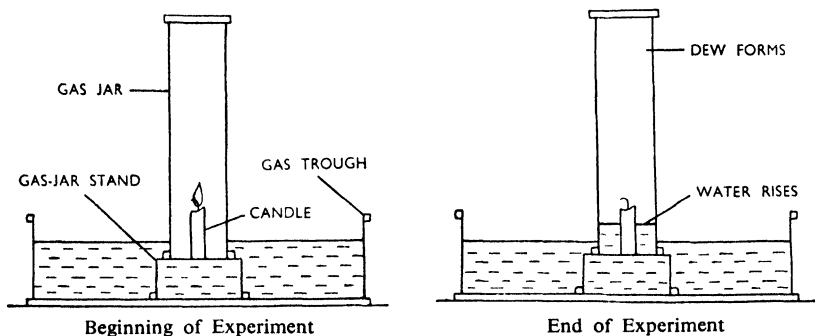


FIG. 3. CANDLE BURNING IN AIR

Put your piece of candle on a wire stand in a trough† containing an inch or two of water. Light the candle and, when it is burning steadily, invert a clean, dry gas-jar over the burning candle.

What happens ?.....

Repeat the experiment with jars of different sizes. In each case, what happens to

- (i) The water-level inside the jar *at first* ?.....
- (ii) The candle flame ?.....
- (iii) The inner surface of the jar ?.....
- (iv) The water-level inside the jar, *finally** ?.....

Repeat the experiment using (instead of the candle) wood (e.g. a match-stick), paper, kerosene† (on cotton-wool) or alcohol† (methylated spirit).†

What happens ?.....

We can now answer the following questions:—

Question

1. Why did the water-level in the jar fall slightly at first ?

2. What is the dew* which forms on the inner surface of the jar ?

3. Why did the candle flame go out after a time ?

4. Why did the water rise in the jar at the end of the experiment ?

Answer

Because the candle flame warms the air in the jar, making it expand.*

It looks like tiny drops of water. Perhaps *steam* (water) is formed when a candle burns? (We are not yet sure about this.)

It seems that a flame cannot go on burning unless it has a free supply of air.

Because part of the air in the jar is used up by the burning candle.

From these experiments, therefore, it seems that *air is made up of at least two different gases, one of which is used up by the burning substance while the other is left behind unused.*

Like the early scientists, we shall call the first gas ‘ *active air* ’, and the second gas, which remains unchanged, we shall call ‘ *inactive air* ’. Burning (or combustion†) seems to depend on the ‘ *active air* ’, hence* this gas is said to *support combustion*, while the other gas, ‘ *inactive air* ’, *does not support combustion*.

WHAT HAPPENS TO THE ACTIVE AIR USED UP IN BURNING ?

We have seen that the ‘ *active air* ’ is used up in our experiments, but where has it gone ? Unless it has been ‘ *destroyed* ’ in some way it must still be inside the jar at the end of the experiment (although perhaps in some other form). Now the only *new* substance we can *see* at the end of the experiment is a little dew, which we think may be water. Perhaps something else has been formed which we cannot see—a gas ? To find if this is so, we shall have to use a *test*, and make the invisible* gas produce something which we can see.

Take a jar filled with fresh air, pour a little lime-water† into it, close the jar with a gas-jar cover, and shake.

What happens ?.....

Repeat this with a jar of air in which a candle has been burned.

What happens ?.....

This is a test for a gas which the early scientists called ‘ *fixed air* ’—formed whenever fuels* burn in air. (Fuels are substances we burn to produce *heat*, e.g. wood, coal, kerosene and petrol,† and they all form ‘ *fixed air* ’ when burnt. Lime-water is made by shaking up quick-lime† with water, allowing the mixture to stand, and then pouring off the clear liquid.)

SCIENTIFIC TESTS

The use of *tests* needs some explanation. In our everyday life we depend on our senses* to know what is going on around us, i.e. by what we can *see*, *hear*, *feel*, *taste* or *smell*. But in our work in science we often have to deal with things which we cannot ‘ *sense* ’. We shall sometimes have to distinguish between several gases which have neither colour, taste, nor smell, and to do this

we shall apply *chemical tests*. For example, we cannot tell if 'fixed air' is present until we make it form something which we can *see*. (The clear lime-water turns 'chalky'.) We shall sometimes have to tell whether one substance is warmer than another when the difference is too small to distinguish by *feeling*, so we shall use a thermometer* and *see* whether the mercury† in it rises or falls. The purpose of all our scientific tests is to produce something which we can *see, hear, feel, taste* or *smell*. In most of our tests we *see* something, although in chemistry* we often make use of our sense of *smell*.

WHAT FRACTION* OF THE AIR IS 'ACTIVE' ?

When we burn fuels in air, the 'active' air is used up, but we know that some 'fixed air' is formed in its place. Hence, although our candle experiments show that a part of the air is used up in burning, we cannot tell exactly what fraction of the air is 'active'. To discover this, we must burn something which, in burning, does not form and leave behind another gas which will mix with the 'inactive air'. The most suitable substance for this purpose is phosphorus† (a substance which can be used for making matches); because when it burns it does not form a gas, but a solid white ash which will dissolve easily in water.

TO FIND WHAT HAPPENS WHEN PHOSPHORUS BURNS IN AIR

Your teacher will show you the following experiment: A metal stand is put in a trough containing a few inches of water, and a small piece of yellow phosphorus¹ is put on top of the stand. A glass bell-jar† is put over the phosphorus, as shown in the diagram, and the level of the water is marked on the side of the bell-jar. The phosphorus is then set on fire by touching it with the hot end of a glass rod which slides through the cork of the bell-jar. The phosphorus burns with a bright light and forms a thick cloud of

¹ Yellow phosphorus is a very dangerous substance which catches fire of itself, without being brought near a flame, in a hot climate. It is stored *under water* and it must *never be touched with the fingers*.

white 'smoke'. After a short time, the phosphorus stops burning, and the water rises in the jar. The white 'smoke' gradually disappears as it dissolves in the water. If the level of the water is marked on the jar at the end of the experiment, it is found that *one-fifth* of the air has been used up by the burning phosphorus. When a lighted wooden splinter* is put into the gas left behind in the bell-jar, the flame goes out at once. If a drop of clear lime-

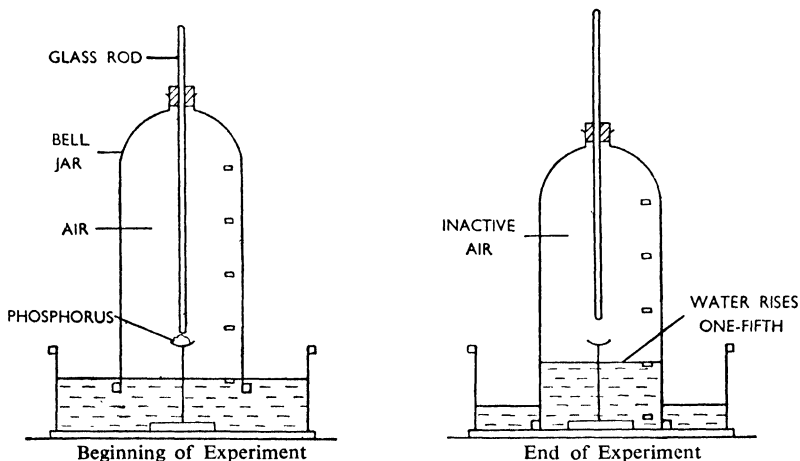


FIG. 4. BURNING PHOSPHORUS IN AIR

water, on the end of a glass rod, is held inside the bell-jar, it remains clear, showing that there is no 'fixed air' in the jar.

We conclude,* therefore, that **air consists of one-fifth 'active air', which supports combustion, and four-fifths 'inactive air', which does not support combustion.**

THE RUSTING OF IRON

We all know that when a piece of ordinary iron,† e.g. an iron nail, is left in a damp place, it *rusts*. We shall now do some simple experiments to find what part the air plays in rusting.

Wet the inside of a long test-tube or gas-jar with water, and put into it enough iron filings* to cover the sides when shaken up. Invert the tube in a dish of water, as shown in the diagram, mark the level of the water inside the tube (with a rubber band), and set it aside until next lesson.

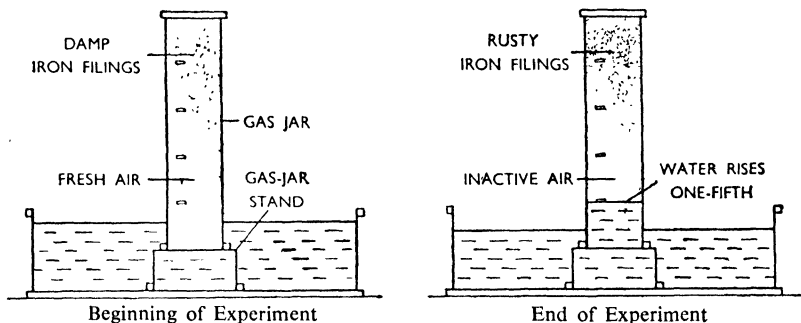


FIG. 5. IRON RUSTING

What happens

(a) to the iron ?.....

(b) to the water-level ?.....

Test with a lighted wooden splinter the gas which remains.

What happens ?

What does this show ?

In another similar experiment test the gas which remains with a drop of lime-water on the end of a glass rod.

What happens ?

What does this show ?

We see, then, that *when iron rusts one-fifth of the air is used up*. This result reminds us at once of our last experiment of burning phosphorus in air. It seems that *rusting is a very similar kind of change to burning or combustion, which the remaining four-fifths of the air will not support*.

WHAT HAPPENS TO THE ACTIVE AIR USED UP BY BURNING PHOSPHORUS AND RUSTING IRON ?

In our experiments on burning fuels, part of the air in the jar disappeared, and also a small quantity of the burning substance. The only new substances formed were (a) the 'dew' on the sides of the jar, and (b) some 'fixed air'. In the 'bell-jar experiment', the only new substance formed was the white phosphorus ash. In the same way, in the experiment on the rusting of iron, the only new substance formed was the iron rust. Perhaps the iron rust and the phosphorus ash contain the active air which disappeared during the experiment? But, if *iron rust* = *iron* + *active air*, then the rust should weigh *more* than the original clean iron. And, in the same way, if *phosphorus ash* = *phosphorus* + *active air*, then the ash should weigh *more* than the original unburnt phosphorus. We can test this by experiment.

TO FIND IF THERE IS ANY CHANGE IN WEIGHT WHEN IRON RUSTS

Put a thin layer* of clean iron filings on a clean watch-glass, and weigh the watch-glass and iron filings. Then wet the iron filings with a few drops of water and set them aside until next lesson. At the beginning of your next lesson, put the watch-glass with the rusty iron filings in a desiccator† (Fig. 96) for half an hour to make sure that it is quite dry, and then weigh it.

Weight of watch-glass and *clean* iron filings = gm.

Weight of watch-glass and *rusty* iron filings = gm.

Hence, *there is a gain in weight when iron rusts*, so it seems that *the iron has taken up (or combined* with) the active fifth part of the air to form iron rust*. We shall now do a similar experiment with burning phosphorus.

TO FIND IF THERE IS ANY CHANGE IN WEIGHT WHEN PHOSPHORUS BURNS

It is clear that we shall have to burn a weighed quantity of phosphorus, catch all the ash that is formed, and then weigh it.

This can be done by using the apparatus* shown in the diagram. The drying-tube 'A' contains fused* calcium chloride† to dry the air as it enters the apparatus. The right-hand end of the glass tube 'B' is loosely packed with asbestos† wool for a length of at least 2 in., to catch the ash from the burning phosphorus, so that it can be weighed at the end of the experiment. About 1 gm. of *red* phosphorus (which has been dried in a desiccator) is put in the middle of tube 'B', and a little asbestos wool is put near the left-hand end of the tube. This tube 'B', containing the *unburnt* phosphorus, is weighed before the experiment. The tubes 'A'

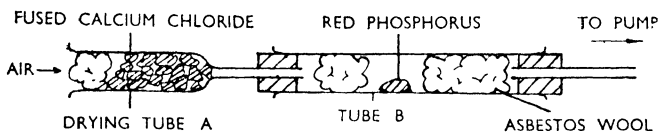


FIG. 6. BURNING PHOSPHORUS IN AIR

and 'B' are then joined together as shown in the diagram, and the other end of 'B' is connected to a filter-pump† (or some other arrangement for drawing a gentle stream of air through the apparatus). The phosphorus in 'B' is then set on fire by heating the tube with a small flame, and the white ash from the burning phosphorus is caught by the asbestos wool. When most of the phosphorus has burnt away, the stream of air is stopped and the tube 'B' is allowed to cool. When it is cool, the tube 'B', which now contains phosphorus ash, is again weighed. (The drying-tube 'A' is necessary because phosphorus ash has a great liking for water and would take up water from ordinary damp air. This would spoil the experiment since we want to compare the weight of the *dry* unburnt phosphorus with the weight of *dry* phosphorus ash.)

Weight of tube and asbestos wool and *unburnt*
phosphorus = gm.

Weight of tube and asbestos wool and
phosphorus ash = gm.

Hence, *the phosphorus ash weighs more than the original, unburnt phosphorus.*

This gain in weight can only have come from the air. But we have seen that one-fifth of the air disappears when phosphorus is burnt under a bell-jar, so we can now explain what has happened to this 'active air'.

The 'active air' combines with the phosphorus to form phosphorus ash, just as iron combines with 'active air' to form iron rust.

These experiments on the rusting of iron and the burning of phosphorus are very important, because they show that when substances burn or rust they combine with part of the air. It was not until about 1772 that men carried out such experiments (*using the balance*) and began to understand the true meaning of *burning* and *rusting*. Before then, they believed that substances *lost* something during burning and rusting !

IMPORTANT CONCLUSIONS* FROM OUR EARLIER EXPERIMENTS

Our experiments prove that the air consists of at least two gases, one of which (active air) is able to combine with iron, phosphorus, and other substances, while the other gas (inactive air) will not combine with these substances. About one-fifth of the air is 'active' and the remaining four-fifths is 'inactive'.

FURTHER EXPERIMENTS ON THE RUSTING OF METALS

(i) Hold a piece of magnesium† wire or 'ribbon' in the crucible† tongs† and heat one end in the Bunsen flame.

What happens ?.....

What is left ?.....

(ii) Hold a piece of thin copper† sheet in the crucible tongs and heat it red-hot in the Bunsen flame (but do not let it melt). Then remove the copper from the flame and allow it to cool.

What do you notice ?.....

Hence *some metals which only rust very slowly at the ordinary temperature will rust rapidly if they are heated.* You will always find that chemical action is made quicker by heating. That is

why you see so many burners in a laboratory*: many of the experiments which we carry out in a few minutes by heating would take *years* to complete at lower temperatures.

TO FIND IF THERE IS ANY CHANGE IN WEIGHT WHEN MAGNESIUM BURNS

Take a porcelain crucible and lid, and heat them in a clean, non-luminous* Bunsen flame, on a fire clay† triangle,* for a few minutes. Then take away the burner and wait until they are cool enough to touch with the finger-tips. You will be given about 20 cm. of magnesium ribbon, which you must clean by drawing it through a folded bit of sand-paper. When the crucible is cool, put the magnesium into it, broken up into short pieces. Then weigh the crucible with its lid and the magnesium, entering the weight below. Put the crucible on a fire-clay triangle and heat it with a clean, non-luminous flame, gently at first, and then strongly. After heating strongly for at least five minutes, lift the crucible-lid *very cautiously*, so as to let in air, but taking great care that no ash escapes. When you see no more bright flashes of light inside the crucible, remove the lid altogether (putting it on the asbestos sheet) and heat the crucible as strongly as possible. When you can see no further change, let the crucible and its contents cool and then weigh them.

Weight of crucible, lid and *magnesium* =gm.

Weight of crucible, lid and *magnesium ash* =gm.

Hence, *the magnesium ash weighs*gm.*than the original, unburnt magnesium*, showing that *magnesium in burning combines with part of the air*, just like burning phosphorus, or rusting iron.

FURTHER EXPERIMENTS ON THE RUSTING OF IRON

We know from our everyday experience that iron rusts in damp air (i.e. air+water). We shall now try to find out *whether both air and water are necessary*, or whether *air alone* (i.e. dry air) or *water alone* (i.e. 'air-free' water) will make iron rust.

TO FIND IF IRON WILL RUST IN DRY AIR

Take an iron nail and rub it with sand-paper until it is quite clean and free from rust. Put the nail in a desiccator and leave it there for several days. Then examine the nail.

What do you notice ?

Your teacher may be able to show you some iron nails which have been kept in a desiccator *for several years*.

Are they rusty ?

Hence, *air alone, without water, will not make iron go rusty.*

TO FIND IF IRON WILL RUST IN WATER WHICH CONTAINS NO AIR

Half fill a test-tube with water and boil it for several minutes to remove all the air. Then stop heating and put a clean iron nail in the hot water. Drop some oil or a small lump of vaseline† (petroleum jelly†) on the surface of the water so as to form an air-tight covering, as shown in the diagram. After about a week, examine this iron nail.

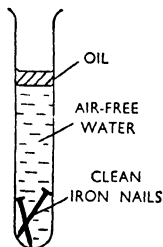


FIG. 7. IRON IN AIR-FREE WATER

What do you notice ?

Your teacher may be able to show you some iron nails which have been kept in air-free water *for several years*.

Are they rusty ?

Hence, *water alone, without air, will not make iron go rusty. Iron will only rust if both air and water are present.*

Although iron and steel (which is a kind of iron) are the commonest *metals* in everyday use, they have one very serious disadvantage—they *rust*. It has been calculated that it costs about £500,000,000 every year to replace all the iron and steel articles in the world which have been spoilt by rusting. It is clear that rusting can be stopped by keeping the air away from the surface of the iron, and there are many practical ways of

doing this. The simplest method is to rub oil over the iron, but the thin layer of oil is easily rubbed off, and then rusting takes place. The commonest method of protecting iron is by painting. When the paint 'dries', it forms an air-tight skin which keeps the air away from the iron. Another common and lasting protection against rusting is a thin layer of some other metal which does not rust so easily, e.g. iron sheets are dipped in melted tin† to make tin-plate, which does not rust until the tin is scratched and the iron is exposed* to the air. Galvanized iron† is made by dipping iron into melted zinc.† Iron is also coated with nickel† and chromium† by electro-plating,† which we shall learn about later.

THE ATMOSPHERE

The atmosphere† is a layer of air, many miles thick, which surrounds the Earth. Our earlier experiments have shown that the air is a mixture of gases and that about one-fifth of its volume is 'active air' (which supports combustion) and about four-fifths is 'inactive air' (which does not support combustion). We shall now give these gases their modern chemical names and mention some other gases which are present in the air in smaller amounts.

'Active air' is now called oxygen† and the more accurate proportion* of oxygen in the air is 21 per cent. The 'inactive air' makes up 79 per cent. of the air, 78 per cent. being nitrogen† while the other 1 per cent. consists of the 'rare gases' which are quite inactive and will not combine with any other substances. Besides these gases, air always contains a very small quantity of 'fixed air' (0.03%) which has the chemical name carbon dioxide.†

The air also contains some water-vapour, but the proportion varies* very greatly, e.g. in the wet Tropics the air contains much water-vapour, while the air over the Sahara Desert contains very little. Air, too, always contains tiny particles* of solid matter, or dust, but the amount of dust in the air varies from place to place and from time to time.

THE COMPOSITION OF DRY AIR—BY VOLUME

Active air	..	Oxygen	..	..	21 % (nearly)
Inactive air	..	Nitrogen	..	..	78 % (nearly)
		Rare gases	..	..	1 % (nearly)
Fixed air	..	Carbon dioxide	..	..	0.03 % (or 300 parts per million)

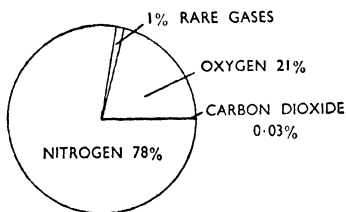


FIG. 8. COMPOSITION OF AIR BY VOLUME

OTHER CONSTITUENTS* OF ORDINARY AIR

Water-vapour	..	Amount varies
Solid matter (dust)	..	Amount varies

OXYGEN

Everyone knows that air is essential* for life. It is the *oxygen* in the air which enables animals and plants to live in it, and without oxygen all living things would die. Oxygen is also necessary for *burning, rusting, and decay*. We shall learn more about this most important gas later.

NITROGEN

The nitrogen in the air takes no active part in breathing, burning, rusting or decay. It serves a useful purpose, however, in diluting* the oxygen and thus slowing down its action. But for the large proportion of nitrogen in the air, burning, decay and rusting would be much more rapid. In later lessons we shall find that although the nitrogen in the air is so inactive, when it is combined with other substances it is extremely important, since it forms an essential constituent of the food of animals and plants, and enters into the composition of all living matter.

THE RARE GASES

The air contains five 'rare gases', but they are so inactive that it would make little difference to the air if they were not present

at all. Although they are called the 'rare' gases, one of them—argon†—is present in the air to the extent* of 0·9 per cent. (i.e. about 9,000 parts per million: 30 times more plentiful in the air than carbon dioxide). Argon is used, mixed with nitrogen, in 'gas-filled' electric light bulbs. Neon† (which forms only 0·0015 per cent. of the air) is used for filling the bright red 'neon lights' used for electric advertising signs. Helium† (which is present to the extent of only 0·0005 per cent., i.e. 5 parts per million) is the most suitable gas for filling airships since although it is very 'light', it will not burn.

Although there are other sources of helium, it is still too rare and expensive for general use in airships and balloons.* (Hydrogen,† the gas which is generally used for this purpose, is even 'lighter' than helium, but it has the great disadvantage that it catches fire very readily.) The other two 'rare gases' are present in the air in even smaller proportions than helium.

CARBON DIOXIDE

If some clear lime-water is put in a watch-glass and exposed to the air for several hours it turns 'chalky', showing the presence of 'fixed air' or carbon dioxide. Although the proportion of carbon dioxide in the air is so small (only 0·03 per cent. or 300 parts per million parts of fresh air) it is extremely important since *green plants in sunlight* take in carbon dioxide from the air and use it for manufacturing substances like sugar† and starch† which form the food of the plant. We shall study this important gas in detail later.

WATER-VAPOUR IN THE AIR

We have all seen that the outside of a glass filled with ice-water very quickly becomes covered with drops of a clear liquid. This is because water-vapour from the air has condensed* on the cold surface. We shall discuss the importance of the water-vapour in the air later.

SOLID MATTER IN THE AIR—DUST

There is always some dust in ordinary air. This dust consists of particles of solid matter which are so small that they float in the air. When seen under the microscope,† dust is found to contain material from many different sources, e.g. unburnt carbon† (soot†) from fires; bits of cotton and wool from clothing; bits of animal hair and skin; rock-dust and very fine sand stirred up by the feet of animals and the wheels of cars and carts, or carried by the wind from bare patches* of earth.

Besides these non-living particles, dust always contains ‘*living dust*’. These living particles are mainly bacteria† and the spores† of moulds.* These spores are small enough to float about in the air until they reach a suitable place to grow. Bacteria are still smaller (often less than 0·001 mm. in length), but in spite of their small size they are very important in everyday life. Some kinds of bacteria cause diseases, but most of them are harmless and even useful. We shall learn more about this ‘*living dust*’ later.

THE CHANGES PRODUCED IN AIR BY BREATHING

(i) Collect some expired* air (i.e. ‘breathed-out air’) as follows:—Fill a gas-jar with water, cover the mouth of the jar with a gas-jar cover, and invert it in a trough of water. Put one end of a glass or rubber tube under the mouth of the jar and blow through the other end until the jar is full of air from your lungs.* Then remove the tube, close the jar with its cover and lift it out of the trough. Invert this jar of expired air over a lighted candle, count the number of seconds until the flame goes out, and enter the figure below. Light the candle again after

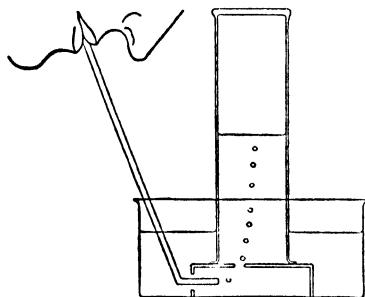


FIG. 9.
COLLECTING EXPIRED AIR

removing the jar, and then invert a similar jar of *fresh air* over the lighted candle, again taking the time for the flame to go out.

The candle burnt for seconds in expired air and for seconds in fresh air.

The candle burns for a shorter time in expired air because there is less oxygen present than in fresh air. The flame does not go out at once, however, showing that breathing does not use up *all* the oxygen.

(ii) (a) Collect another jar of expired air. Pour some clear lime-water into the jar, close with a gas-jar cover, and shake.

What happens ?.....

(b) Pour some clear lime-water into a jar of fresh air, close with a gas-jar cover, and shake.

What happens ?.....

What do you learn from experiments (a) and (b) ?.....

.....

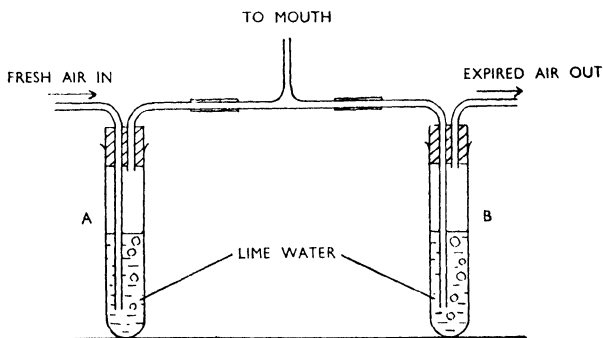


FIG. 10. CHANGES PRODUCED IN AIR BY BREATHING

(iii) Using the apparatus shown in the diagram, first draw fresh air through some clear lime-water in tube 'A', and then, after it has been in your lungs, breathe it out again through the

lime-water in tube 'B'. Breathe in and out in this way for some time.

What happens ?.....

What does this show ?.....

.....

QUESTIONS

1. Give one reason for thinking that burning, breathing and rusting are similar chemical* changes.
2. The air we breathe *in* contains oxygen than the air we breathe *out*, and carbon dioxide. (Write one word in each space.)
3. What is the *safest* gas to use for filling airships ?
4. What is the usual test for carbon dioxide ?
5. What is the percentage of ' active air ' in the atmosphere (by volume) ? %
6. What is the percentage of ' fixed air ' in the atmosphere (by volume) ? %
7. What gas forms 78 per cent. of the atmosphere, by volume ?

them are so *active* that your teacher will merely show them to you, demonstrating* some of their properties.

ALUMINIUM	MAGNESIUM	POTASSIUM	PHOSPHORUS	PLATINUM†
IRON	CALCIUM	SODIUM	CARBON	SILVER†
COPPER	LEAD†	MERCURY	SILICON	CHROMIUM
ZINC	TIN	IODINE†	SULPHUR	NICKEL

Write short descriptions of these elements (about two or three lines) mentioning only the more striking properties in each case. Underline the METALS in the above list.

MATTER AND ITS CHANGES

Another simple method of classifying materials is to divide them into *solids*, *liquids*, and *gases*. For example, at room temperature iron is a solid, water is a liquid and air is a gas. It is important to be clear about the characteristics of these *three states of matter*.

A solid has a definite* shape and size (or *volume*) and force is required to change this shape (although force will seldom change the volume of a solid). Some of the hardest work in the world is done in changing the shape of solids, e.g. all wood-work and metal-work, digging earth, and breaking rocks. This resistance to change of shape is sometimes expressed by saying that *solids are rigid*.*

A liquid has a definite size (volume) but it has no definite shape. There is no difficulty in changing the shape of a liquid. For example, if we pour water from a square pint bottle into a round pint bottle the water immediately *takes the shape of the containing vessel* (a very different business from trying to force an iron rod, 1 inch square, into a round hole of 1 square inch cross-section* in a block of iron). The size, or volume, of the liquid, however, is unchanged and we cannot force more than a pint of water into a pint bottle. When a liquid does not completely fill the containing vessel its upper surface is horizontal.

A gas (or vapour) has neither definite shape nor size—it immediately takes the shape of any vessel into which it is put, and always

completely fills the vessel. Thus, if we take a large vessel from which all the air has been removed, and let into it a little air, this quantity of air, however small, will immediately expand to fill the vessel. On the other hand, we can take a vessel which is already 'full' of air and, by using a bicycle pump, we can force in twice as much air. That is to say, air, like all other *gases*, has no fixed volume and can be either compressed* or made to expand.

There are many important everyday applications of these different properties of solids, liquids and gases. When an article of complicated shape has to be made of iron, it is very much easier to pour *liquid iron* into a mould* of sand of the required shape, than to cut or file the article from a block of *solid iron*. In the same way, liquid concrete† is poured into wooden moulds and then allowed to become solid in shapes which would be very difficult to cut from a piece of solid rock. Liquid clay, too, is easily shaped into bricks which become rigid solids after heating. 'Plastics'* like 'bakelite'† make use of the same principle* of changing the shape of the material while it is in the liquid state.

CHANGE OF STATE—PHYSICAL* CHANGE

When solid ice is heated it melts to form liquid water, and when water is boiled it becomes a gas—steam.

Although *ice*, *water* and *steam* have those names, they are only different forms, or *states*, of the same substance—*water*. *Ice* is *solid water*; and *steam* is *gaseous water* or *water vapour*. When ice melts to form water, therefore, it is only a *change of state*. Such changes of state are called *physical changes* because they are studied in more detail in the branch of science called *Physics** than in the branch of science called *Chemistry*.

A physical change is one in which no new substance is formed.

Only the physical state changes and the change is usually easy to reverse,* e.g. water can be changed into steam by heating, while steam can be changed back to water again by cooling. There is no change in weight during a physical change, e.g. 100 gm. of water will give 100 gm. of steam when boiled or 100 gm.

of ice when frozen. Except in the case of water (where we have different names for the different states—ice, water, steam) we keep the same name for all three states, e.g. solid *air*, liquid *air*, and *air* (the gas); or solid *sulphur*, liquid *sulphur*, and *sulphur* vapour; thus showing that there is no change of *substance*.

CHANGE OF SUBSTANCE—CHEMICAL CHANGE

When magnesium burns in air, two substances—magnesium, a solid metal, and oxygen, a colourless gas—combine together to form a third substance—white magnesium ash: heat and light being produced during the process.* The magnesium ash is clearly *an entirely new substance*. It weighs more than the original magnesium and it is impossible to get back metallic magnesium from the white ash without using some other substance to remove the oxygen. Such a *change of substance* is called a *chemical change*.

A chemical change is one in which new substances are formed, with entirely different properties.

You will find, however, that in most of your chemical experiments you are using physical means to produce and control chemical changes, e.g. *mixing* substances together, *heating* substances, passing *electric currents* through substances. We shall refer later to this close relationship between *chemistry* and *physics*.

TO EXAMINE SOME PHYSICAL AND CHEMICAL CHANGES

(i) Take a piece of nichrome† wire (a mixture of nickel and chromium), roll it into a spiral coil,* and weigh it. gm.

Hold it with the crucible tongs in the hottest part of the Bunsen flame.

What happens ?

Remove the nichrome wire from the flame and let it cool.

Weigh it again. gm.

Compare its appearance with that of some nichrome wire which has not been heated. Can you see any difference ?

What kind of change does nichrome wire undergo when heated ?

Why do you say this ?.....

.....
(ii) Hold a piece of magnesium wire with the crucible tongs in the edge of the Bunsen flame.

What happens ?.....

Is there any change in weight ? (See p. 13.).....

What kind of change is this ?.....

Why do you say this ?.....

.....
(iii) Heat a little paraffin† wax very gently, holding the test-tube about $\frac{1}{2}$ in. above a small flame.

What happens ?.....

Pour the hot wax into some cold water in an evaporating dish.†

What happens ?.....

Compare the final product with the original wax.....

What kind of changes are these ?.....

Why do you say this ?.....

.....
(iv) (a) Heat a little red mercuric oxide† (mercury rust—*poison*) in a small, dry test-tube, heating only gently.

What is the first change you see ?.....

Allow the tube to cool again.

What happens ?.....

What kind of change did the mercuric oxide undergo when heated *gently* ?.....

Why do you say this ?.....

.....
(b) Now heat the mercuric oxide very strongly, putting a red-hot wooden splinter in the mouth of the tube from time to time.

What happens to the splinter ?.....

What happens to the mercuric oxide ?.....

When there is no further change, stop heating and allow the tube to cool.

What do you notice when you examine the tube ?.....

What kind of change does mercuric oxide undergo when heated *strongly* ?.....

Why do you say this ?.....

(v) Take a piece of 'soft' iron and hold it over a few iron filings. Will it pick up the filings ?.....

Now put the 'soft' iron on the end of a bar-magnet† and hold it over the filings.

What happens ?.....

Why ?

Will the soft iron still pick up iron filings after the bar-magnet is removed ?.....

Why ?

What kind of change has the iron undergone ?.....

Why do you say this ?.....

(vi) Put a small lump of freshly-burnt quick-lime in an evaporating dish. Add water to it, drop by drop, until there is no further change.

What do you see ?.....

What kind of a change is this ?.....

Why do you say this ?.....

(vii) Close the end of a bicycle pump tightly with the left fore-finger and then push in the handle of the pump.

What happens to the air inside the pump ?.....

Now let go of the handle. What happens ?.....

Why ?

What kind of changes did the air in the pump undergo ?.....

Why do you say this ?.....

(viii) Put about 10 c.cm. of blue copper sulphate† solution* in a test-tube (three inches in a five-eighths inch test-tube) and then add a small, *clean*, iron nail.

What happens

(a) at first ?.....

(b) after a long time ?.....

What kind of a change is this ?.....

Why do you say this ?.....

(ix) Put a *small* piece of iodine in a clean, *dry* test-tube and heat it gently over a small flame.

What happens ?.....

Stop heating when there is no further change at the bottom of the tube and allow it to cool. (*Take care !* Do not invert the tube during the experiment.)

What happens ?.....

What kind of change has the iodine undergone ?.....

Why do you say this ?.....

(x) (a) Put a little sugar on a crucible lid (or on a piece of broken porcelain*) and heat it *very gently*.

What happens ?.....

Allow it to cool.

What happens ?.....

What is the taste of the substance ?.....

What kind of change did the sugar undergo when heated *gently* ?

Why do you say this ?.....

(b) Now heat the sugar strongly.

What happens ?.....
What kind of change does sugar undergo when heated *strongly* ?
.....

Why do you say this ?.....
.....

PHYSICAL AND CHEMICAL PROPERTIES OF MATTER

For convenience, the scientific study of the properties of matter is usually divided into two branches—*Physics* and *Chemistry*. In this General Science Course there is no need to separate completely these two closely related subjects (in any case, you cannot go very far in ‘chemistry’ without knowing some ‘physics’); but as we shall often use the terms *physical* and *chemical* it is important to know what these terms mean.

Physics is the study of the effects of the different forms of energy† on matter.

The scientific meaning of ‘energy’ will be explained in later lessons. For the present it is enough to remember that *heat*, *light*, *sound*, *electricity*, and *movement* are all *forms of energy*. We say that a dynamo† is a source of electrical energy; a loud-speaker† is a source of sound energy; a coiled-up clock-spring is a source of energy of movement; burning wood is a source of heat energy; the sun is a source of light energy; and so on.

Physics deals with the effects of these different forms of energy on matter, but only so far as they change the *properties* of materials *without changing their chemical composition*, i.e. without producing entirely new substances.

Chemistry also deals with changes of matter; but during *chemical changes*, substances change not only their properties but also their *chemical composition*, and entirely new materials are produced.

In this Science Course you will soon realize the importance of *accurate description*, and in describing the properties of any material it is convenient to group its properties, or qualities, into two classes:—(i) *physical properties*; (ii) *chemical properties*.

In describing the *physical properties* of a substance we state
(a) whether it is a solid, a liquid, or a gas at the ordinary temperature;

(b) its colour;

(c) its taste (if any);

(d) its smell (if any);

(e) its density† (that is to say, in the case of a solid or a liquid, whether it is 'heavier' or 'lighter' than water; or in the case of a gas, whether it is 'heavier' or 'lighter' than air);

(f) whether it dissolves in water;

(g) its melting-point (i.e. the temperature at which a solid melts) and its boiling-point (i.e. the temperature at which a liquid boils).

In the case of a solid we also say if it is hard or soft, and if it is a gas we also say whether it is easily changed to a liquid.

The *chemical properties* of a substance are those which describe what it does (and what it does *not* do) in Nature and in the laboratory; that is to say the chemical changes which it undergoes to produce entirely new substances of different composition. For example:

(a) whether it burns in air;

(b) whether it allows other things to burn in it (if the substance is a gas);

(c) whether it splits up when heated and, if so, what substances are formed;

(d) how it reacts* with other substances.

By always following this plan we shall be able to give complete and accurate descriptions of all the materials we study.

As an example, let us describe the properties of air (as far as we can with our present knowledge):—

Air† is a gas without colour, taste or smell. It dissolves in water. It does not burn, but it allows things to burn in it (i.e. it supports combustion). It is not decomposed by heat. It has no immediate action on lime-water.

To take another example:—Mercuric oxide is a red powder

with no smell. (As it is poisonous we do not describe its taste.) It is very 'heavy' and it does not dissolve in water. When heated, it first turns black and then splits up into mercury and oxygen.

Describe the following materials on the same plan:—Water; magnesium; petrol; iron; quick-lime; paraffin-wax; yellow phosphorus; sugar.

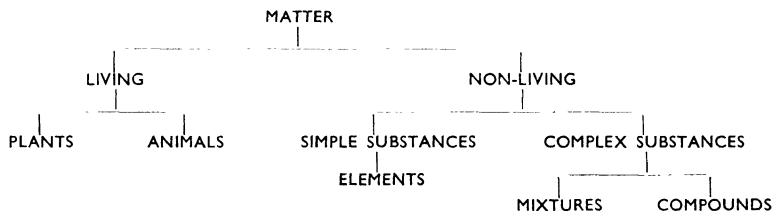


FIG. 11. THE CLASSIFICATION OF MATTER

MIXTURES AND COMPOUNDS

One way of classifying all the materials in the world is to distinguish between (a) the substances which are chemically *simple*, and (b) the substances which are chemically *complex*,† i.e. between substances consisting of *only one kind of matter* and those consisting of *two or more different kinds of matter*. Out of all the hundreds of thousands of different substances in the world, there are only 92 which have never been split up into simpler substances, hence our group of *chemically simple substances* is limited to the *elements*, and we have seen that only a small proportion of these are met with, free and uncombined, in everyday life. Most everyday materials are very complex and contain several elements, and these complex materials are classified into groups of materials with similar properties. The two main groups of *complex materials* are (a) MIXTURES and (b) COMPOUNDS. Although there is not much difference between the everyday meanings of these two words, there is a clear distinction between their scientific meanings.

Two substances can be put together in two different ways:

(a) They may form a *mixture* in which both substances are present with their original properties unchanged. For example, air is a *mixture* of oxygen and nitrogen.

Or (b) they may *combine together* and undergo a *chemical change* to form an entirely new substance in which the original substances do not keep their original properties. For example, iron rust is not a mixture of iron and oxygen, for it shows none of the properties of either iron or oxygen: it is a compound of iron and oxygen in which the two elements are held together by chemical force.

The chemical names given to compounds tell us what elements they contain. Thus, the chemical name for iron rust is iron oxide†, because it is a compound of iron and oxygen. Similarly, the white ash formed when magnesium burns is *magnesium oxide*.†

Mixtures are composed of two or more substances which are NOT held together by chemical force.

Chemical compounds consist of two or more elements which are bound together by chemical force.

Hence the three main groups in the *chemical classification of matter* are ELEMENTS, MIXTURES, and COMPOUNDS.†

There are so many thousands of chemical *compounds* that it is necessary to classify them into further groups, each group consisting of compounds of similar chemical composition and with similar properties. You will learn about various classes of chemical compounds later.

A chemical compound is the result of a chemical change; and in order to separate a compound into its constituents it is necessary to overcome the chemical force which is holding the constituents together. The constituents of a mixture, on the other hand, are not bound together by chemical force and they can therefore be separated by *physical* means, without using a chemical reaction. The following example will illustrate the differences between the properties of mixtures and compounds.

COMPARISON OF THE PROPERTIES OF A MIXTURE OF IRON AND SULPHUR
WITH THOSE OF A COMPOUND OF IRON AND SULPHUR

(i) Examine the properties of the element iron:—

Take some iron filings.

What is their colour ?.....

Hold a magnet over the iron.

What happens ?.....

(ii) Examine the properties of the element sulphur:—

Take some powdered sulphur.

What is its colour ?.....

Put a *very small quantity* of sulphur in a dry test-tube and add
1-2 c.cm. (half-inch) of *carbon disulphide*.†

What happens ?.....

(iii) Examine the properties of a *mixture* of iron and sulphur:—

Thoroughly mix together some iron filings and powdered
sulphur in a mortar.†

What is the colour of the mixture ?.....

What can you see with a lens* ?.....

What happens when you hold a magnet over the mixture ?
.....

Put a little of the mixture on a *dry* filter-paper, in a funnel*;
place a clean, dry watch-glass underneath, and then pour
1-2 c.cm. of carbon disulphide on the mixture.

What happens ?.....
.....

This shows how *the constituents of a mixture keep their own
original properties unchanged*, and also how *the constituents of a
mixture can be separated by simple, physical means*.

(iv) Examine the properties of a *compound* of iron and sulphur:

Put the rest of your mixture of iron (5 parts) and sulphur
(3 parts) in an old test-tube and lay it horizontally on a wire gauze†
on a tripod† stand. Put your burner under the closed end of the

† Never take carbon disulphide near a flame as it catches fire very readily. If
you have to warm carbon disulphide, hold the vessel containing it in hot water and
NOT over a flame.

tube and watch carefully what happens. Remove the burner as soon as you see a striking change.

What happens ?.....

What is left ?.....

Remove the residue* from the test-tube (it may be necessary to break the tube in order to do this), and hold it in the flame with the crucible tongs.

Is there any further change ?.....

Allow it to cool, and then crush it up in the mortar. Examine the compound of iron and sulphur*—*iron sulphide*†—with a lens.

Can you see any grey iron ?.....

Or any yellow sulphur ?.....

Hold a magnet over it.

What happens ?.....

Put a small quantity of the compound in a dry test-tube and add 1-2 c.cm. of carbon disulphide. Warm the tube in hot water, shake, and then filter on to a clean watch-glass.

Does the carbon disulphide remove any sulphur ?.....

This shows how *the properties of a compound are quite different from those of its constituents*, and how *the constituents of a compound (being held together by chemical force) cannot be separated by simple, physical means.*

DIFFERENCES BETWEEN MIXTURES AND COMPOUNDS

We can now summarize* the important differences mixtures and compounds.

MIXTURES

1. *The constituents of a mixture may be mixed together in any proportions, i.e. the composition of different mixtures of the same constituents may vary.*

COMPOUNDS

The constituents of a compound are always present in fixed and definite amounts, i.e. different samples of the same compound always have exactly the same composition.

2. *In a mixture, each constituent keeps its own original properties.*

3. *The constituents of a mixture lie side by side as separate particles and there is no chemical force binding them together.*

4. *The constituents of a mixture can be separated by simple, physical means, without employing chemical reactions.*

5. *When a mixture is made there is little or no change in temperature.*

The properties of a compound are quite different from those of its constituents.

Compounds are the products of chemical changes and their constituents are bound together by chemical force.

The constituents of a compound cannot be separated by physical means but only by means of chemical changes.

When a compound is made there is a change in temperature, i.e. heat is given out or taken in during the chemical change.

EXAMPLES OF MIXTURES

Air (nitrogen, oxygen, etc.), granite† (quartz,† felspar† and mica†), brass† (copper and zinc), solder† (tin and lead), garden soil.

EXAMPLES OF COMPOUNDS

Magnesium oxide, iron sulphide, carbon dioxide, mercuric oxide, copper sulphate, iron oxide.

THE SEPARATION OF MIXTURES INTO THEIR CONSTITUENTS

As the separation of mixtures into their constituents is an important operation in many industries, we shall now discuss a few methods of separation by physical means, without using any chemical changes.

(a) A mixture of particles of different sizes can be sorted out by using a sieve,* e.g. in separating a mixture of sand and stones.

(b) Any magnetic material can be separated from a powdered mixture by using a magnet, as in separating wolfram† (magnetic) from tin-ore† (non-magnetic); or in removing particles of iron from foodstuffs which have been ground up between steel rollers.

(c) If one constituent is 'lighter' than the others it can be carried away with a stream of air or water, as in winnowing* grain; and washing for tin-ore.

(d) Sometimes one constituent can be dissolved in a liquid, leaving the other constituents undissolved. Thus salt can be extracted from a mixture of earth and salt by means of water; gold† can be extracted* from crushed gold-bearing quartz by dissolving it in mercury.

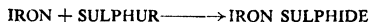
(e) If one constituent melts at a lower temperature than the others, it will flow away when the mixture is heated. For example, sulphur is found mixed with earth and rock; and when the mixture is heated the sulphur melts and flows away.

(f) In a mixture of liquids, if one constituent boils at a lower temperature than the others it can be separated by distillation.* Crude* petroleum,† as it comes from an oil-well, is a mixture of a large number of different substances. When it is boiled, petrol distils* off first, then kerosene, and so on.

How could you separate the following mixtures in the laboratory? (i) Salt and sand. (ii) Petrol and water. (iii) Sand† and clay.† (iv) Iron and brass filings. (v) Alcohol and water. (vi) Gunpowder† (a mixture of charcoal,† sulphur and nitre†). (vii) Iodine and powdered glass.

A SHORT WAY OF WRITING CHEMICAL REACTIONS

We can represent any chemical change or reaction in this way:



Each *name* stands for a *substance*. Two substances which are *mixed* but not chemically combined are joined by the + sign. The arrow* \longrightarrow shows where the *chemical change* takes place, and also the direction of the change. In words, this statement reads:

Iron and sulphur, when brought together in a suitable way, combine chemically to form iron sulphide.

In later lessons, when you understand *chemical formulas** (or *formulae*), we shall shorten these statements still further into *chemical equations*.*

CHEMICAL NAMES

Notice that there is nothing separating the words '*iron*' and '*sulphide*' in the name *iron sulphide*. This shows that the iron and the sulphur are *chemically combined* or bound together by chemical force.

Notice, also, that the chemical name of a substance tells you exactly what elements it contains.

[If the chemical name ends in *-ide*, then the compound contains only *two* elements, e.g. magnesium oxide, calcium carbide,† hydrogen sulphide,† and sodium chloride.†]

If the chemical name ends in *-ate*, then the compound contains *oxygen* as well, e.g. copper sulphate, calcium carbonate, sodium phosphate, potassium nitrate.]

You will soon realize that *chemical names* tell you much more about substances than *common names*. For example, the chemical name for *common salt*† is *sodium chloride*. The name '*common salt*' tells you nothing about its chemical composition, but the name '*sodium chloride*' shows that it is a compound of the elements '*sodium*' and '*chlorine*' *and nothing else* (since it ends in *-ide*). Similarly, the chemical name for *washing soda*† is *sodium carbonate*, showing that it is a compound of sodium, carbon *and oxygen*. So there is nothing to be afraid of in these chemical names. In fact, the longer they are the more they tell you about the substance.

SOLUTIONS

When a little common salt is shaken up with plenty of water for a few minutes, we can no longer see the salt; and however long we let it stand, the salt does not settle out again. The salt

is said to have *dissolved* in the water, and the uniform* mixture of salt and water is called a *solution* of salt in water.

On the other hand, when a little starch is shaken up with water we get a cloudy mixture. If we look at it closely, we can still see bits of starch scattered throughout the water; and when we let

it stand for a few minutes, the starch settles down to the bottom. The starch was not dissolved, but only suspended* in the water. That is, we do not get a solution of starch in water, but only a suspension.* When we filter this suspension, all the starch is left on the filter-paper; but if we filter the solution of salt, nothing remains on the filter-paper, and in order to get back the

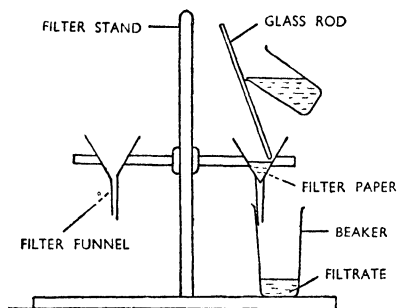


FIG. 12. FILTERING

salt we have to *evaporate* the salt solution to dryness.

SOLVENTS

Every liquid is a solvent* for some substance or other, e.g. carbon disulphide dissolves sulphur and rubber, or it is a solvent for these two substances; petrol is a solvent for oil, grease or wax; alcohol is a solvent for shellac† (the mixture forms varnish†); turpentine† dissolves linseed† oil (the mixture is used for polishing and preserving laboratory woodwork); mercury will dissolve many other metals; while water is a solvent for thousands of different substances.

What solvents would you use to remove spots of the following substances from your clothes ?—(a) tar,† (b) sugar, (c) gum.†

EXPERIMENTS WITH SOLUTIONS

(i) Half fill a test-tube with water and add about 1 gm. of nitre (potassium nitrate).† Shake the test-tube vigorously,* closing the mouth of the tube with your thumb.

What happens ?.....

What is formed ?.....

Place the test-tube in the test-tube stand for a few minutes.

Is there any change on standing ?.....

Now add more nitre, about 1 gm. at a time, shaking vigorously after each addition.

What happens at first ?.....

What happens after several additions of nitre ?.....

.....

When no more nitre will dissolve, filter the liquid into a clean, dry test-tube. This filtrate* (i.e. the clear liquid which passes through the filter) is a saturated† solution of nitre, because you went on adding nitre until the solution could hold no more, i.e. the water was *saturated* with nitre. Pour about 5 c.cm. (one and a half inches in a five-eighths inch test-tube) on to a clean watch-glass and put it on the water-bath to evaporate. (Keep the remainder of your saturated solution of nitre for a later experiment.) Examine the dry residue on the watch-glass and keep it for comparison with the results of the next two experiments.

(ii) Repeat Experiment (i), using about 1 gram of slaked lime† instead of nitre.

Does *all* the slaked lime dissolve ?.....

Does *any* slaked lime dissolve ?

To make sure of this, filter the liquid and evaporate about 5 c.cm. of the filtrate to dryness on a watch-glass as in Experiment (i).

Is there any residue, and if so, how much ?.....

Is slaked lime more or less soluble* than nitre ?.....

(iii) Again repeat the experiment, using about 1 gm. of finely powdered limestone† or 'chalk '† (but *not* 'black-board chalk'). Filter the mixture and evaporate 5 c.cm. to dryness as before.

Is there any residue, and if so, how much ?.....

Is limestone more soluble or less soluble than lime ?.....

SOLUBILITY

Your experiments show that different substances dissolve in water in varying amounts, e.g. nitre is readily soluble in water, lime is slightly soluble in water, while limestone is practically *insoluble*. The amount of a substance which is required to *saturate* a fixed amount of the *solvent* is called its *solubility*.

The solubility of a substance is the number of grams required to saturate 100 grams of the solvent at a definite temperature. For example, at 30° centigrade,† 100 gm. of water will dissolve 45 gm. of nitre, i.e. the *solubility* of nitre at 30° C. is 45. In the same way, 100 gm. of water at 30° C. will dissolve 36 gm. of common salt, i.e. the solubility of common salt at 30° C. is 36. Again, 100 gm. of water at 30° C. will dissolve 0·15 gm. of slaked lime, i.e. the solubility of slaked lime at 30° C. is 0·15.

By expressing the relative* solubility of different substances by a *number* we get a much more accurate idea than by using terms like 'very soluble', 'readily soluble', 'slightly soluble', 'practically insoluble', etc.

THE EFFECT OF TEMPERATURE ON SOLUBILITY

Take the saturated solution of nitre which you made in Experiment (i) and warm it slightly. Add about 1 gm. of nitre and shake.

What happens ?.....

Is nitre more soluble in hot water than in cold water ?.....

Warm your solution still more and add another 1 gm. of nitre.

What happens ?.....

Filter your warm solution into a small beaker and set it aside to cool.

What happens ?.....

What is the effect of rise of temperature on the solubility of nitre ?.....

CRYSTALS AND CRYSTALLIZATION

We have seen that the solubility of nitre is much greater in hot water than in cold water, therefore, if we saturate some hot water with nitre and then allow it to cool, it will become *more than saturated* at this lower temperature and some solid nitre will come out of the solution. For example, the solubility of nitre at 30°C . is 45, while its solubility at 80°C . is 170: hence, if we saturate 100 gm. of water with nitre at 80°C . the solution can hold 170 gm. of nitre, but if we let this hot solution cool to 30°C . it can hold only 45 gm. of nitre. The excess of solid nitre ($170-45=125\text{ gm.}$) will therefore separate from the solution in solid form.

This excess of nitre does not separate out anyhow, but in particles of definite regular shape called crystals,[†] and these crystals ‘grow’ as more and more solid nitre separates from the solution. If the cooling is slow, a few large crystals are formed; but if the cooling is rapid, a lot of very small crystals are formed.

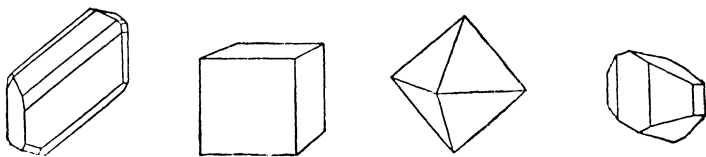


FIG. 12A. SOME SHAPES OF CRYSTALS

When examined with a lens, however, the tiny crystals are seen to have exactly the same geometrical shape as the larger ones.

Your teacher will put drops of various saturated solutions on glass slides under the microscope or micro-projector[†] so that you can watch the crystals growing as the solution slowly evaporates. Notice that crystals of different substances have different characteristic shapes. In fact, many substances can be recognized by the shape of their crystals.

WATER OF CRYSTALLIZATION

Certain substances, as they crystallize, combine with definite amounts of water, called water of crystallization (or water of

hydration). Such substances, containing water of crystallization, are called hydrates.[†] Although these crystals appear to be quite 'dry', they may contain a lot of water *combined* with the solid in its crystalline state. Thus copper sulphate crystals (copper sulphate hydrate) contain 36 per cent. of water; washing-soda[†] crystals contain 63 per cent. of water of crystallization. It is important to remember that this water is *combined* with the solid, hence the crystals appear quite dry to the touch.

Many substances, however, crystallize from their solutions without combining with any water, e.g. nitre and common salt. Such crystals, which contain *no water of crystallization*, are said to be anhydrous[†] (without water).

TO EXAMINE SOME CRYSTALS CONTAINING WATER OF CRYSTALLIZATION

- (i) Half fill a test-tube with washing soda (sodium carbonate[†] crystals or sodium carbonate hydrate) and fit the tube with a cork carrying a delivery tube,

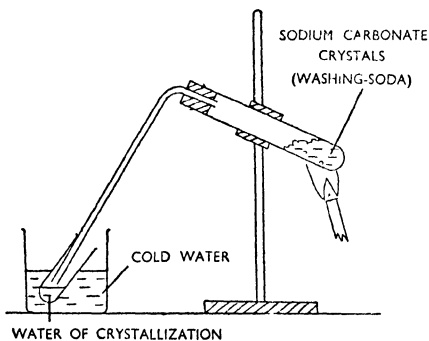


FIG. 13. WATER OF CRYSTALLIZATION

as shown in the diagram. Clamp[†] the tube in a sloping position and let the delivery tube dip into a dry test-tube standing in a beaker of cold water. Gently heat the washing soda with a *small* flame. The solid appears to melt, but it is actually

[†] This word *hydrate* was formerly applied to substances we now call hydroxides,† so if you sometimes see reagent* bottles labelled* 'Calcium Hydrate', 'Sodium Hydrate', 'Ammonium Hydrate' and 'Potassium Hydrate', remember that the modern name is 'Calcium Hydroxide', 'Sodium Hydroxide', 'Ammonium Hydroxide', and 'Potassium Hydroxide'.

dissolving in its own water of crystallization. Continue heating until the soda looks quite dry, allow to cool, and then examine the contents of both test-tubes. The dry residue is 'soda ash' (or *anhydrous sodium carbonate*) while the clear liquid in the other tube is the water which was combined with the soda as water of crystallization.

(ii) Repeat Experiment (i), using blue copper sulphate crystals (or copper sulphate hydrate) instead of washing soda, and continue heating gently until a nearly white powder is obtained.

After cooling, put a little of this *anhydrous copper sulphate* in a dry test-tube and add water, drop by drop, from the tap.

What happens ?

Anhydrous copper sulphate is white, and the blue colour of copper sulphate crystals is due to their water of crystallization. Hence anhydrous copper sulphate (white) can be used as a *test for water*, and we shall use it for this purpose later.

(iii) Put *one drop* of a strong solution of cobalt chloride† on a piece of filter-paper, or blotting-paper, and dry it by holding several inches above a *small* flame, being careful not to burn the paper.

What happens ?

Breathe on the spot of *anhydrous cobalt chloride*.

What happens ?

Hence 'cobalt chloride paper' can be used as a delicate test for water, e.g. we can make use of it to show whether our desiccators are working properly by sticking a piece of cobalt chloride paper inside. When the air inside the desiccator is dry, the paper is blue, but as soon as the air becomes damp the paper turns pink, showing that the desiccator needs fresh fused calcium chloride.

CHEMICAL DRYING AGENTS

Some substances, after their water of crystallization has been driven off by heat, take up water again when exposed to damp air, e.g. the fused calcium chloride in your desiccators was made by

heating calcium chloride crystals (or calcium chloride hydrate) until all the water of crystallization was driven off. The fused (or anhydrous) calcium chloride takes up water again whenever it can, actually absorbing enough water to dissolve itself. Examine some fused calcium chloride which has been exposed to the air of the room for half an hour, on a watch-glass.

QUESTIONS

1. Write down the definition of a *chemical change*.
2. Name the three states of matter.
3. Name **ten** common elements.
4. Name one element which is a liquid at ordinary temperatures.
5. Name the constituents of *calcium carbide*.
6. Define the term 'chemical compounds'.
7. Which is 'heavier', water or paraffin wax ?
- How do you know ?
8. Name the constituents of iron rust.
9. What is the common name for *potassium nitrate* ?
10. Name the constituents of iron sulphate.
11. Define the term 'elements'.
12. How would you get metallic copper from some copper sulphate crystals ?
13. What is the white solid used in desiccators ?
14. Write **one** word which means 'the clear liquid which has passed through the filter'.
15. What apparatus would you use to evaporate a liquid **very** gently ?

CHAPTER III

THE GASES OF THE AIR

OXYGEN

Our earlier experiments showed that the air contains about one-fifth (21 per cent.) of 'active air' or oxygen. We have seen that this gas is a most important substance since all life depends on oxygen; without it we should suffocate,* and it is necessary for burning, rusting and decay.

We have ourselves prepared a little oxygen by heating red mercuric oxide (p. 26). This was how Priestley discovered oxygen in 1774. About a year later, Lavoisier, a French chemist,

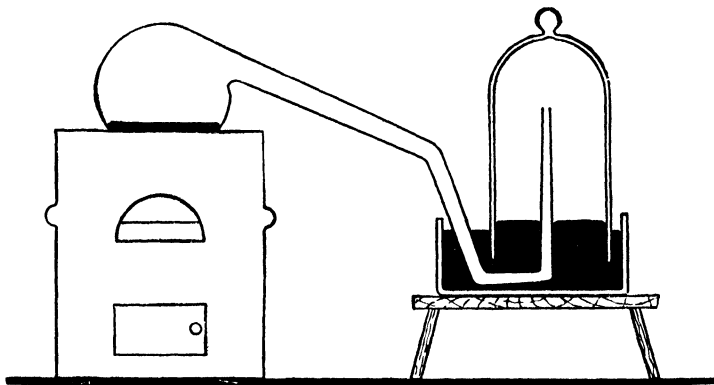


FIG. 14. LAVOISIER'S EXPERIMENT

carried out some experiments which showed clearly the composition of the air and what actually happens when metals burn or rust in air. In Lavoisier's most famous experiment, he heated some mercury in the apparatus shown in the diagram. Mercury

rust formed on the surface of the hot mercury, and at the same time the mercury rose in the bell-jar. After heating the mercury at a temperature near its boiling-point for twelve days and nights, there was no further change, so the heating was stopped. After cooling, the volume of air left in the whole apparatus was *four-fifths* that of the original air, and this air which was left would not support combustion, i.e. the gas was what we now call *nitrogen*.

Having measured the volume of air which had disappeared in his experiment, Lavoisier went on to find out where the missing fifth had gone, so he collected all the red mercury rust, heated it strongly, and collected the gas which was given off. The volume of this gas was the same as that of the air which had disappeared in the first experiment. When a red-hot wooden splinter was put in the gas it burst into flame, in fact, the gas was what we now call *oxygen*.

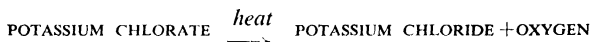
Lavoisier then mixed this one-fifth of oxygen with the four-fifths of nitrogen and found that the mixture had exactly the same properties as ordinary air. In this historical experiment, therefore, Lavoisier first analysed* air and then synthesized* it. The oxygen of the air combined with the heated mercury to form mercuric oxide, and, when this was strongly heated, the oxygen was set free once more, pure and free from any nitrogen.

THE PREPARATION OF OXYGEN IN THE LABORATORY

We shall now prepare oxygen in larger quantities and examine its properties. We have already obtained a little oxygen by heating red mercuric oxide, but this method is too slow and too expensive for us to use in making large quantities of oxygen, so we shall now use *potassium chlorate*.† (Mercuric oxide costs about twelve times as much as potassium chlorate and yields only one-fifth as much oxygen, i.e. oxygen prepared from mercuric oxide costs about sixty times as much as oxygen prepared from potassium chlorate.) As we can see from its name, potassium chlorate is a compound of potassium, chlorine and oxygen. It

contains much oxygen (nearly 40 per cent. by weight), and for this reason it is also used in making matches and fireworks.

Heat a few grams of potassium chlorate in a dry test-tube. Notice that it first melts to a clear liquid. Continue heating until bubbles of gas begin to come off, and then test the gas by putting a red-hot wooden splinter in the mouth of the tube. The splinter bursts into flame. This is the simplest test for oxygen, for no other common gas will do this. Allow the test-tube to cool. The white solid left behind after all the oxygen has been driven off is *potassium chloride* (the name shows that it contains *only potassium and chlorine*). Written briefly



In preparing oxygen by heating potassium chlorate, we have to heat the test-tube very strongly before any gas is given off; in fact, an ordinary test-tube of 'soft' glass begins to melt. Your next experiment shows how this difficulty can be overcome.

THE EFFECT OF MANGANESE DIOXIDE ON THE DECOMPOSITION OF POTASSIUM CHLORATE

(i) Put 2 gm. of *potassium chlorate alone* in a dry test-tube and heat it *steadily* in the Bunsen flame. Hold a red-hot wooden splinter *at the mouth of the tube* and note how long it takes to burst into flame.seconds.

(ii) Now take a similar test-tube and put in it *a mixture of 2 gm. of potassium chlorate and 0.5 gm. of manganese dioxide*.† Repeat the above experiment, *heating the tube in the same part of the same flame as before*. How long is it before the red-hot wooden splinter bursts into flame?seconds.

Your experiments show that manganese dioxide makes the potassium chlorate set free its oxygen much more smoothly and at a much lower temperature (actually about 200° C. instead of 600° C.). The manganese dioxide only hastens the decomposition of the potassium chlorate, and itself remains unchanged after all the oxygen has been set free from the potassium chlorate. Such

a substance is called a catalyst.† We shall come across other catalysts later.

{Catalysts are substances which change the speed of a chemical reaction but themselves remain unchanged at the end of the reaction.

TO PREPARE SEVERAL JARS OF OXYGEN

Thoroughly mix about 9 gm. of potassium chlorate with about 3 gm. of manganese dioxide. Put the mixture in a 'hard' glass test-tube and put together the apparatus shown in the diagram.

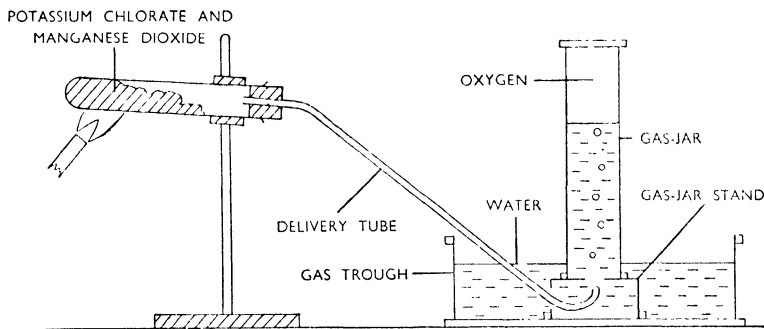


FIG. 15. PREPARATION OF OXYGEN

The test-tube is clamped loosely in a horizontal position and is fitted with a good cork carrying a delivery-tube. The other end of the delivery-tube dips under a gas-jar stand in a gas-trough which is half-filled with water. When the teacher has approved your apparatus, heat the test-tube *gently*, moving the flame about all the time. (N.B.—If you put the burner under the tube and leave it there, you will probably break the tube. Also be careful that the hot mixture of potassium chlorate and manganese dioxide does not touch the cork. Why?.....) When bubbles of gas begin to come out of the delivery-tube, allow the first few bubbles to escape. (Why?.....) Then invert a test-tube, full of water, over the end of the delivery-tube.

Collect four test-tubes and three gas-jars of oxygen, closing the test-tubes with corks and the gas-jars with gas-jar covers. (N.B.—If the gas is cloudy, you are heating the test-tube too strongly.) As soon as you have collected enough oxygen, raise the end of the delivery-tube above the surface of the water in the gas-trough. (Why ?)

1st Tube. (a) Has the gas any colour, taste or smell ?.....

(b) Hold a red-hot wooden splinter in the gas.

What happens ?.....

Does oxygen burn ?.....

2nd Tube. Invert the tube of oxygen in a beaker containing a little water and leave it until the end of the lesson.

Does oxygen dissolve in water ?.....

Why do you say this ?.....

3rd Tube. Pour a little *purple litmus† solution* into the tube of oxygen, close with the thumb and shake.

What is the action of oxygen on litmus ?.....

4th Tube. Pour a little clear lime-water into the tube of oxygen, close with the thumb and shake.

What is the action of oxygen on lime-water ?.....

1st Jar. Lower a short piece of lighted candle into the jar.

What happens ?.....

2nd Jar. Put a piece of wood-charcoal (carbon) on a gas-jar spoon and heat it red-hot in the Bunsen flame. Then put it in the jar of oxygen (being careful not to let it touch the sides of the jar).

What happens ?.....

After the charcoal has finished burning, take out the spoon, add a little lime-water, close the jar with a gas-jar cover, and shake.

What happens ?.....

This is a test for carbon dioxide, which you have *synthesized* by burning the element carbon in the element oxygen.

3rd Jar. Put a little *red phosphorus* in a cool, dry gas-jar spoon, and set fire to it by just touching it with a flame. Put the burning phosphorus into the jar of oxygen.

What happens ?.....

What is formed ?.....

FURTHER EXPERIMENTS WITH OXYGEN

Your teacher will prepare several jars of oxygen and show you the following experiments:—

(i) *Burning Sulphur in Oxygen*.—When some sulphur is put in a gas-jar spoon and held in the flame, it melts and catches fire, burning with a faint blue flame which can hardly be seen in daylight. When put into a jar of oxygen, it burns with a much brighter blue flame, forming a cloudy gas which has a characteristic pungent* smell.

This gas is sulphur dioxide.† When a little water is put in the jar and shaken up, the sulphur dioxide dissolves in the water, forming *sulphurous acid*† (*not sulphuric acid*). As this is the first time that we have made an acid† we must now learn what this word means.

Acids are substances which have a SOUR taste and change the colour of litmus† (a dye* obtained from a kind of moss†) from blue to RED. (*Danger.* Do not taste any chemical unless told to do so.)

When some blue litmus solution is put into the jar in which sulphur has been burnt in oxygen, it is turned *red* by the sulphurous acid. Hence, *blue litmus is used in testing for acids*.

(ii) *Burning Carbon in Oxygen*.—When a piece of red-hot wood-charcoal (a form of carbon) is put in a jar of oxygen, it burns quickly, with bright sparks,* and forms a colourless gas, *carbon dioxide*, which, as we have seen in our earlier experiments, turns lime-water ‘chalky’. When shaken up with water, some of the carbon dioxide dissolves, and the solution will *just* turn

blue litmus solution *red*, showing that a *weak acid* has been formed. This weak acid, formed when carbon dioxide dissolves in water, is called carbonic acid.†

(iii) *Burning Phosphorus in Oxygen*.—Phosphorus burns in oxygen with a bright, yellow flame, forming clouds of phosphorus pentoxide.† (As there are several different oxides of phosphorus, they all have different names and this one is called phosphorus pentoxide.) When shaken up with water, this white powder dissolves and the solution turns blue litmus *red*, showing that an acid has been formed. This acid, formed when phosphorus pentoxide dissolves in water, is called phosphoric acid.†

Experiments (i) to (iii) show that when the elements sulphur, carbon and phosphorus burn in oxygen they form oxides which all dissolve in water to form acids.

(iv) *Burning Sodium in Oxygen*.—When a piece of sodium is heated in the flame and then put into a jar of oxygen, it burns quickly with a bright yellow flame and forms a cloud of white sodium oxide.† This sodium oxide dissolves in water and the solution turns red litmus *blue*, showing that no acid is formed in this case, but something else called an alkali.†

Alkalis are substances which have a BITTER (or soapy) taste, and which change the colour of litmus from red to BLUE. Hence litmus is used in testing for both acids and alkalis.

When an acid and an alkali are mixed in the right proportions, they neutralize* each other and form substances which are neither acid nor alkaline, but neutral.* For example, when the strong acid, hydrochloric acid† is mixed in the right proportions with the strong alkali caustic soda,† the product is harmless neutral *sodium chloride* (or *common salt*) which is neither acid nor alkaline and has no action on litmus.

(v) *Burning Magnesium in Oxygen*.—Magnesium burns in oxygen with a blinding white light and forms white magnesium oxide. This dissolves in water slightly, and the solution turns red litmus *blue*, showing that an *alkali* (magnesium hydroxide)† is present.

(vi) *Burning Calcium in Oxygen*.—When the metal calcium is burnt in oxygen there is a bright red light and calcium oxide,† a white solid, is formed. This calcium oxide is slightly soluble in water and the solution turns red litmus *blue*, showing that an *alkali* (calcium hydroxide†) has been formed. When the calcium oxide is shaken up with water it forms a white suspension of calcium hydroxide. On filtering, a clear liquid is obtained which turns ‘chalky’ when shaken up with expired air, showing that the liquid is *lime-water*—synthesized from calcium, oxygen and water.

(vii) *Burning Iron in Oxygen*.—When a piece of thin iron wire is heated red-hot and quickly put into a jar of oxygen it burns rapidly with bright sparks, forming a blue-black *iron oxide*. (This is not the same oxide of iron as the one in iron rust and as it attracts iron filings it is called magnetic iron oxide.†) This oxide will not dissolve in water, hence it cannot form an acid or an alkali and can have no action on litmus.

A SUMMARY OF OUR EXPERIMENTS ON BURNING ELEMENTS IN OXYGEN

Our experiments show that these seven elements can be classified in two groups according to whether they produce acid-forming or alkali-forming oxides.

(a) *When **non-metals** (e.g. carbon, sulphur, phosphorus) burn in oxygen they form **acidic oxides** which combine with water to form **acids**.*

(b) *When **metals** (e.g. sodium, calcium, magnesium, iron) burn in oxygen they form **basic oxides** and those basic oxides which dissolve in water form **alkalis**.*

Later on we shall deal in more detail with these three important classes of compounds—*acids, bases† and alkalis*.

THE PROPERTIES OF OXYGEN

Oxygen is a gas without colour, taste, or smell. It is slightly ‘heavier’ than air.

(Oxygen is sixteen times ' heavier ' than hydrogen, the lightest of all gases, while air is a little over fourteen times heavier than hydrogen.)

Oxygen is only slightly soluble in water, although enough of it dissolves to supply water-plants and animals with the oxygen they require.

(100 c.cm. of water at 0° C. dissolves about 5 c.cm. of oxygen —as the temperature of the water rises the solubility of oxygen becomes less.)

The most important chemical property of oxygen is its power of supporting combustion: any substance that will burn in air burns much more rapidly in oxygen. Oxygen is essential for breathing, burning, rusting and ordinary decay, and all such chemical changes, where substances combine with oxygen, are called oxidations.†

Oxygen is the most plentiful element in the Earth's crust (including the seas and the atmosphere).

BREATHING

As we breathe, air is taken into the lungs at every breath. In the lungs the blood takes up oxygen and loses carbon dioxide, becoming bright red in colour. In its circulation* round the body, this *oxygenated blood* loses oxygen and takes up carbon dioxide, formed by the oxidation of waste products. By the time it reaches the heart again after completing its circulation round the body the blood is dark red in colour. This *de-oxygenated blood* then passes into the lungs where it gives up carbon dioxide and takes up oxygen, the carbon dioxide being breathed out.

The air we breathe in (fresh air) contains about 21 per cent. of oxygen, 78 per cent. of nitrogen and 0·03 per cent. of carbon dioxide. The air we breathe out (expired air) contains about 16 per cent. of oxygen, 78 per cent. of nitrogen and 4 per cent. of carbon dioxide, i.e. the air we breathe *out* contains over 100 times as much carbon dioxide as the air we breathe *in*.

THE COMMERCIAL PREPARATION AND EVERYDAY USES OF OXYGEN

Since the atmosphere contains about 21 per cent. of oxygen, this is the cheapest source of the gas, and most of the oxygen used for industrial purposes is now obtained from the air. The air is first liquefied by great cooling (to about -200°C.), giving a mixture of *liquid oxygen and liquid nitrogen*. If this *liquid air* is allowed to evaporate, the nitrogen boils off first (at -196°C.) leaving liquid oxygen behind. The liquid oxygen is then allowed to boil (at -188°C.) and the oxygen gas, as it comes off, is forced by pumps into strong steel cylinders.

Oxygen is used by doctors when the patient's lungs are not working properly, e.g. in cases of suffocation by drowning or by poisonous gases. It is also used under conditions where ordinary breathing is difficult or dangerous, e.g. by airmen flying at great heights and by mine rescue workers.

Oxygen is used in very large quantities for producing very hot flames for cutting and welding* metals, e.g. the *oxy-hydrogen flame* (hydrogen burning in oxygen) gives a temperature of over $2,000^{\circ}\text{C.}$, while the *oxy-acetylene† flame* (acetylene† burning in oxygen) gives a temperature of over $3,000^{\circ}\text{C.}$ This is hot enough to 'cut' through a steel plate one foot thick.

NITROGEN

Our early experiments showed that about four-fifths of the air is 'inactive air'—mainly *nitrogen*. Nitrogen can be obtained from the air by removing the oxygen, but the gas obtained in this way is not quite pure since it still contains the 'rare gases' and a little carbon dioxide.

We have learnt that Lavoisier, in 1775, was the first man to prove that air is made up of two different gases, oxygen and nitrogen, and that the oxygen alone combines with metals during rusting and burning (p. 9). We shall not use Lavoisier's method to prepare nitrogen, using mercury to remove the oxygen, because the action is so slow (Lavoisier's experiment took about twelve

days). By using *phosphorus* to remove the oxygen we can carry out a similar experiment in about twelve minutes.

TO OBTAIN SOME NITROGEN (AIR MINUS* OXYGEN)

Fix a crucible-lid on a flat cork floating in a gas-trough half-filled with water, and put a small piece of *yellow phosphorus* (DANGER !) on the lid. Set fire to the phosphorus by touching it with a hot wire, and quickly invert a gas-jar over the burning phosphorus. The phosphorus, in burning, combines with the oxygen of the air, forming phosphorus pentoxide, which we see

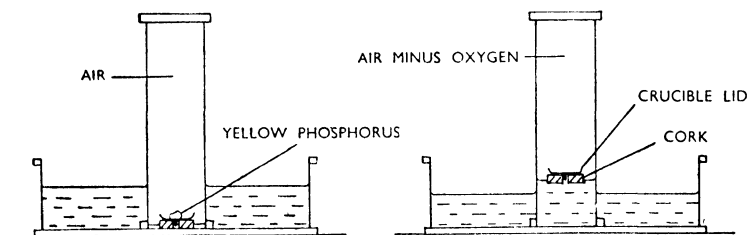


FIG. 16. NITROGEN FROM AIR

as a cloud of white powder filling the jar. After a time, the phosphorus pentoxide dissolves in the water, leaving nitrogen in the jar. Each pair of pupils now has one jar about four-fifths full of nitrogen, and as there are several experiments to do they must be done by different pupils. (The teacher may supply you with jars of nitrogen prepared by a more difficult method.)

(i) Describe the colour, taste and smell of nitrogen.....

(ii) Find out whether the gas is soluble in water.....

(iii) Does nitrogen support combustion? Test this with
(a) a lighted candle, (b) burning sulphur, and (c) burning phosphorus (red).....

(iv) Test a jar of nitrogen with lime-water.

What happens ?.....

How could you distinguish between nitrogen and carbon dioxide ?

.....

THE PROPERTIES OF NITROGEN

Nitrogen is a gas with neither colour, nor taste, nor smell. It is slightly 'lighter' than air.

(Nitrogen is fourteen times heavier than hydrogen, the lightest of all gases, while air is a little over fourteen times 'heavier'.)

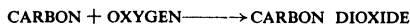
It is only slightly soluble in water (less soluble than oxygen). Nitrogen does not burn itself and it does not support combustion.

Nitrogen has no action on litmus and it does not turn lime-water 'chalky'. You will see that we have spoken of all the things that nitrogen will *not* do. In fact, we have not noticed anything that it *will* do. This is because *nitrogen is so very inactive that it is not easy to make it combine with other elements*. Oxygen, on the other hand, is *very active* and combines easily with most other elements.

We have now prepared and examined the properties of the two chief constituents of the air, oxygen and nitrogen. These two gases together make up nearly 99 per cent. of the air. The remaining 1 per cent. is mainly *argon*, and there is also a very small quantity of *carbon dioxide*, but although there is so very little of the latter, yet it is extremely important in everyday life.

CARBON DIOXIDE

Carbon dioxide is formed when we burn charcoal (carbon) in air or in oxygen. Written briefly,



Carbon dioxide is always formed when any substance containing the element *carbon* is burnt in air or oxygen. All our common *fuels* (substances burnt to provide *heat*), e.g. wood, charcoal, coal and oil, are chemical compounds containing carbon,

and when they burn in air they form carbon dioxide. Carbon dioxide is also formed during *breathing* and during *decay*.

TO SHOW THAT CARBON DIOXIDE IS FORMED WHEN FUELS BURN IN AIR

Hold a clean, *dry* gas-jar for a few seconds over each of the following (do not let the flame touch the glass or you may break the jar): (a) a burning wooden splinter, (b) a lighted candle, (c) the flame of an oil lamp (burning kerosene), (d) the flame of a spirit lamp (burning alcohol), (e) a *small* Bunsen flame (burning).

Is there any change in the appearance of the jar in each case ?

(a) (b)

(c) (d)

(e)

After each experiment, add a little clear lime-water, close the mouth of the jar with a gas-jar cover, and shake.

What happens in each case ?

.....

What does this result show ?

.....

TO SHOW THAT CARBON DIOXIDE IS FORMED DURING BREATHING

Breathe out into a clean, dry test-tube.

Is there any change in the appearance of the tube ?

.....

Add a little clear lime-water, close the mouth of the tube with the thumb and shake.

What happens ?

What does this result show ?

.....

TO SHOW THAT CARBON DIOXIDE IS FORMED DURING DECAY

Set up the apparatus shown in the diagram. Put clear lime-water in the test-tubes ' B ' and ' C ' and some decaying leaves in the flask ' A '.

What happens when air is drawn through the apparatus ?—

(i) To the lime-water in ' B ' ?.....

(ii) To the lime-water in ' C ' ?.....

What does this result show ?.....

What is the object of using the tube ' B ' ?.....

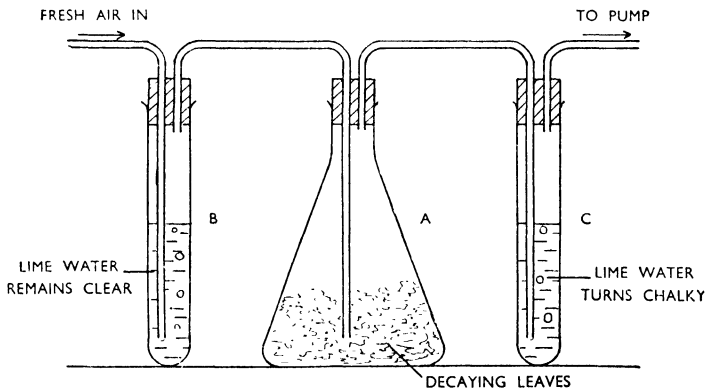


FIG. 17. CARBON DIOXIDE FORMED DURING DECAY

Hence, carbon dioxide is formed in everyday life by (a) the burning of fuels, (b) the breathing of living things, and (c) the decay of plant and animal remains.

THE CIRCULATION OF CARBON DIOXIDE IN NATURE

Burning, breathing, and decay have been going on in the world for thousands of years, and the total amount of carbon dioxide formed during all those years must have been very great indeed. Yet there is only about 0·03 per cent. of carbon dioxide in the air and this proportion always stays practically the same. The percentage of carbon dioxide in the air remains very small because *green plants use a lot of carbon dioxide from the air.* They use

the *carbon* to build up their roots, stems, branches, leaves, flowers and fruits; and they return the *oxygen* to the air in place of the carbon dioxide that they take in. We shall now show that this is so in the case of a green water-plant, and in later lessons we shall show that the same is true of a land plant.

TO SHOW THAT GREEN PLANTS TAKE IN CARBON DIOXIDE AND SET FREE OXYGEN IN SUNLIGHT

Fit up two large flasks as shown in the diagram. Fill flask 'A' with water through which carbon dioxide has been bubbled for some time, i.e. a solution of carbon dioxide. Fill flask 'B'

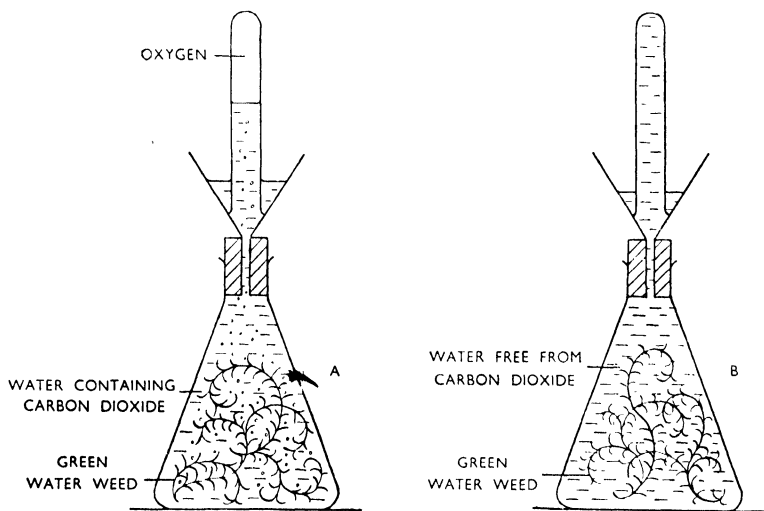


FIG. 18. OXYGEN SET FREE BY GREEN LEAVES IN SUNLIGHT

with water which has been boiled to drive out any carbon dioxide and then cooled in a closed vessel. Put some *green water weed* in both flasks and put them *in bright sunlight* out-of-doors. Invert a test-tube filled with water in each funnel.

Notice that bubbles of gas are formed on the leaves of the plant in flask 'A' (but not in 'B'). In time these bubbles rise and collect in the test-tube. When there is enough gas to test, remove the test-tube, closing the mouth of the tube with the thumb, and put a red-hot wooden splinter in the gas. It bursts into flame, showing that the gas is mainly *oxygen*. In the other flask 'B', where the water contains no carbon dioxide, no oxygen is given off. As the only difference between 'A' and 'B' is that 'A' has carbon dioxide while 'B' has not, the experiment shows that *the plant can only set free oxygen if it is supplied with carbon dioxide*, i.e. **green plants, in sunlight, take in carbon dioxide and set free oxygen.**

This is why the amount of carbon dioxide in the air is always about the same, 0·03 per cent: the green plants which cover so much of the earth's surface use up the millions of tons of carbon dioxide formed each day by burning, breathing and decay as fast as it is formed, and give out oxygen in its place. Hence the air keeps 'fresh' and fit to breathe. If there were no green plants, the oxygen of the air would be steadily used up during burning,

breathing and decay, and carbon dioxide would take its place, so that, in time, the air would no longer be fit to breathe.

These facts concern all of us in our everyday life, and this use of carbon dioxide by green plants in sunlight is one of the most important processes in Nature. Indirectly, through plants, carbon dioxide provides all our food. Rice, wheat and sugar are all plant products. We can only get meat to eat

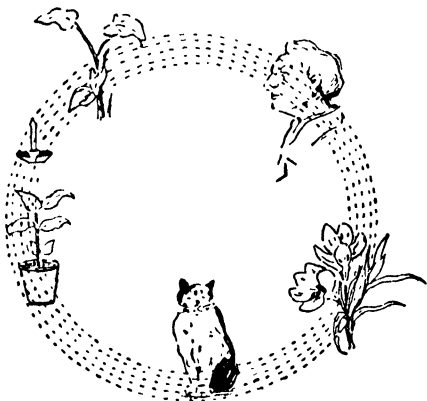


FIG. 19. WHAT BREATHING AND BURNING TAKE OUT OF THE AIR, THE PLANTS PUT BACK

so long as other animals have green plants to feed on. Even our clothes come from plants (e.g. cotton, rubber) or from animals which feed on plants (e.g. wool, silk, leather). The wood we use as a fuel and for so many other things was made from the carbon dioxide of the air. The coal which drives steam engines is only the remains of green plants which lived millions of years ago. The diagrams of 'The Carbon Cycle'*† summarize all these changes.

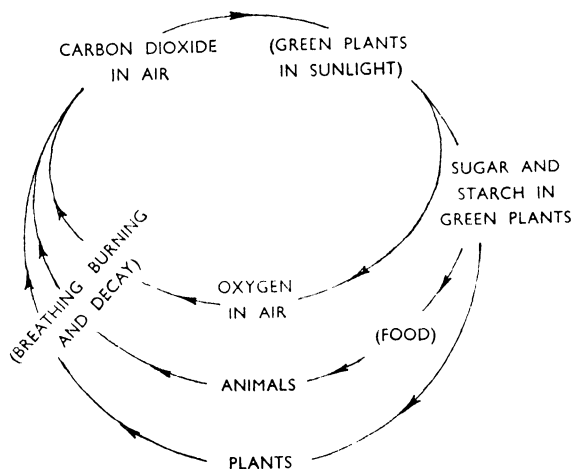


FIG. 20. THE CARBON CYCLE

We see, therefore, that **all life depends upon green plants being able to use the carbon dioxide of the air in sunlight.** *We breathe out carbon dioxide as a waste product, but the green plants change it back again into useful things.* We shall learn a lot more about this wonderful process later.

QUESTIONS

1. Phosphorus oxide turns litmus solution
2. Why does a strong wind make a fire burn more rapidly ?

3. What is the most important chemical property of oxygen ?
4. What name do you give to substances which alter the speed of a chemical change but themselves remain unchanged at the end of the reaction ?
5. What is the usual test for oxygen ?
6. Name the gas which green plants use in sunlight.
7. Name the gas mainly given off by green plants in sunlight.
8. Name the substances formed when potassium chlorate is strongly heated until there is no further change.
9. Name one common form of the element carbon.
10. What natural processes add *more* carbon dioxide to the atmosphere ?
11. What natural processes *remove* carbon dioxide from the air ?
12. Sodium-oxide turns litmus solution
13. Why does a red-hot wooden splinter not burst into flame when held in *air* ?
14. What substances are formed when mercuric oxide is heated ?

CHAPTER IV

PLANT LIFE

LIVING AND NON-LIVING THINGS

We are now beginning the study of plants, and the first thing to be quite clear about is that *plants are alive*. They need *air*, *water*, and other *food materials* to *breathe*, *feed*, and *grow*. They can *move of themselves*, without being pulled or pushed by any outside force, and they also produce *seeds* which grow up into new plants of the same kind. Remember, therefore, that plants, like animals, are living things and that

- (i) **all living things breathe, feed, and grow,**
- (ii) **all living things can move of themselves** (although plants do not move so much as animals), and
- (iii) **all living things can reproduce themselves.**

THE CHIEF PARTS OF A FLOWERING PLANT

The first thing to do is to learn the names of the chief parts of a plant and to get a rough idea of what part each plays in the life of the plant as a whole. The chief parts of an ordinary flowering plant are (a) the *root*, (b) the *stem*, (c) the *leaves*, (d) the *flowers*, (e) the *fruits*, and (f) the *seeds*. The first three—root, stem and leaves—are always present, but the last three—flowers, fruits and seeds—are produced only occasionally during the life of the plant.

We shall now examine a Balsam† plant as an example of a typical* flowering plant, because it grows readily and can be found in almost every garden. There is seldom any difficulty in finding a Balsam plant which has flowers, fruits, and seeds, all at the same time.

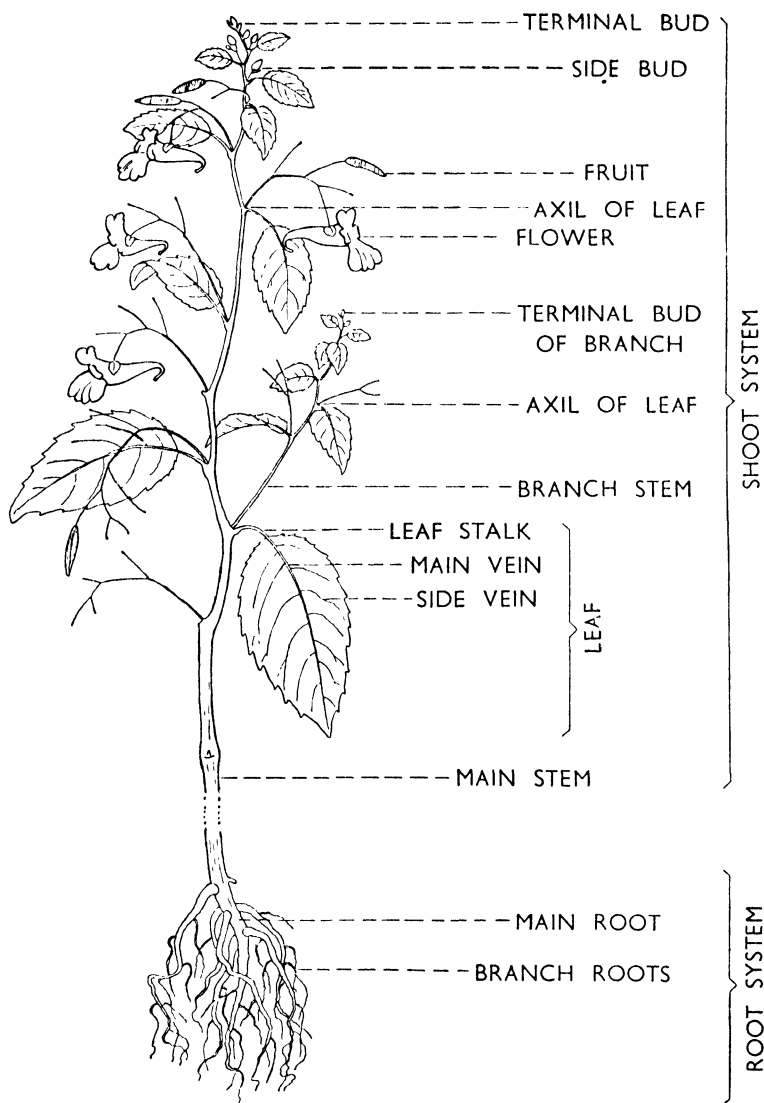


FIG. 21. BALSAM

THE ROOT

The root grows in the ground and it has two main uses:—

(i) *The root takes in, from the soil, water containing dissolved mineral* matter.* (ii) *The root holds the plant firmly in the ground.*

When we dig up a Balsam plant *very carefully*, we find that the roots have pushed themselves through the soil in all directions in their search for water, thus holding the plant firmly. If the root is washed gently under a tap so as to remove the soil without breaking the smaller roots, we find that the *main root* usually grows straight downwards, while the *branch-roots* slope outwards and downwards.

THE STEM

The stem usually grows straight upwards above the ground because its main use to the plant is *to hold up the leaves in the best position for getting as much light as possible.* The stem also carries food materials from the roots to the leaves and manufactured food from the leaves to the roots. At times, the stem also displays* the flowers.

The *main stem* bears leaves and *branch-stems*. Each leaf grows on a *leaf-stalk*, and the acute* angle between the stem and a leaf-stalk is called the axil† of the leaf. Buds† and branch-stems grow in the axils of leaves. These branches slope outwards and upwards, bearing green leaves. The top of the stem ends in a bud, called the terminal bud,† consisting of small, folded leaves.

THE LEAVES

The leaves grow from the main stem and its branches. They are thin, flat, and green in colour, and they are held out in a nearly horizontal position where they will receive as much light as possible. The upper side of the leaf is smooth and slightly darker in colour than the under side. The main vein† is an extension of the leaf-stalk down the middle of the leaf, and *branch-veins* run out on either side of the main vein to the edges of the leaf.

These branch-veins divide up into still smaller veins which join together to form a network which forms the 'skeleton'† of the leaf. The green leaves are a very important part of the plant since *they build up the plant's food from the carbon dioxide of the air and the water supplied by the roots, with the help of sunlight.*

THE FLOWERS

A plant like a Balsam always has a root, stem, and leaves, but during the later part of its life it usually bears flowers and fruits as well. The flowers grow from the stem, in the axils of leaves, and their only use to the plant is *to produce fruits and seeds.* Since the Balsam, like many other plants, needs the help of *insects* to do this, the flowers are *coloured* and *sweet-smelling*, and *they contain a sugary liquid called nectar†* (which bees make into honey†). The young flower is enclosed and protected in a *flower-bud* until it is ready to open.

THE FRUITS

After the flowers have been open for some time, the coloured part dries up and falls off, but the green parts of the flower usually remain on the plant and grow bigger, forming the fruit,† which contains a large number of small *seeds*. The use of the fruit to the plant is, first, *to protect the seeds*, and then *to scatter them.* The Balsam has an 'explosive' fruit, for when the seeds are ripe, a slight touch makes the dry fruit fly open or explode, throwing the seeds some distance away from the parent plant. (N.B.—The scientific term 'fruit' means 'that part of the plant which contains the seeds', whether we can eat it or not.)

THE SEEDS

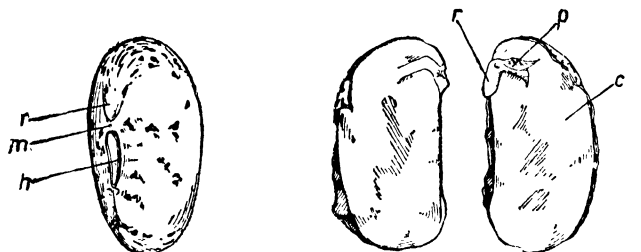
A ripe seed is really *a very young plant*, with the beginnings of a root, a stem, and leaves, so that it can grow up into a new plant. In this way, plants *reproduce* themselves.

It is often convenient to classify all these plant parts into two main *systems* of parts:—(a) the root-system† (consisting of the main root and the branch roots), and (b) the shoot-system† (consisting of all the parts which grow above the ground—main stem, branch stems, leaves and flowers).

SEEDS AND SEEDLINGS*

THE BEAN SEED

A dry bean† seed feels quite hard and is covered with a skin or *seed-coat*. On one side of the seed can be seen a scar† which



SOAKED BEAN SEED

SOAKED BEAN SEED OPENED

FIG. 22

shows where the seed was once attached to the fruit (the bean-pod†) (see *h* in picture). After bean seeds have been soaked in water for some hours, they become very much larger in size and they feel softer. A tiny hole (*m*) can now be seen near one end of the scar, and if the soaked seed is pressed between finger and thumb, a little water comes out of this opening. This is where most of the air and water needed for the growth of the seed gets in. The seed-coat can now be easily removed from the soaked seed and it is found to be quite thick and tough. When the seed-coat has been taken off, we find that the greater part of the seed is made up of two large, fleshy *seed-leaves* (*c*), full of food material ready to feed the young plant until it is able to make its own food. The seed-leaves are joined together near the scar

by the young *seed-plant*, and the tip of the *seed-root* (*r*) sticks out from between the seed-leaves. If the seed-leaves are pulled apart, the *seed-shoot* (*p*) is found between them. This is a short stem with some tiny yellow *leaves* folded together at the end of the seed-stem. These tiny yellow leaves later become the first green leaves of the young plant.

THE MAIZE GRAIN

A maize† grain also shows a scar where it was attached to the cob.† On one flat face of the grain there is a light-coloured,

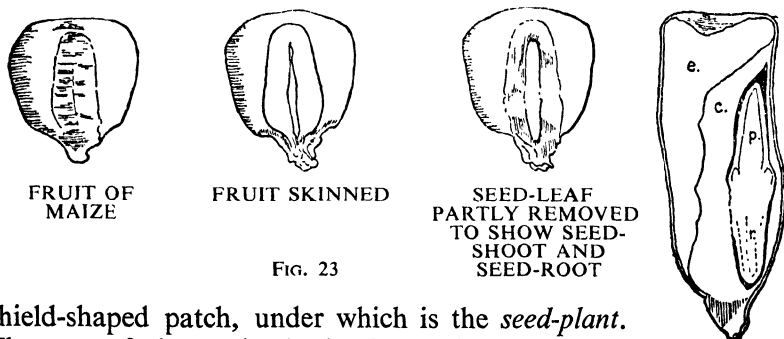


FIG. 23

shield-shaped patch, under which is the *seed-plant*. The rest of the grain is food-material (*e*) stored *outside the seed-plant*, and not inside the seed-leaves (*c*) as in the bean. If a soaked maize grain is cut through with a sharp knife down the middle of one of its flat faces, the seed-plant can be seen. It is very small, but with a lens we can see that there is *only one seed-leaf* (*c*), which surrounds the seed-root (*r*) and the seed-shoot (*p*). If we take another soaked maize grain, we can dissect* out the tiny seed-plant. First cut through the outer coat, down the middle of the shield-shaped patch, and through the outer part of the seed-leaf. Turn back the cut edges and then take out the seed-plant with the help of two needles (or pins). This needs great care, as the seed-plant is very small and is easily damaged. Examine it with a lens and recognize the seed-root and the seed-shoot.

THE GERMINATION OF SEEDS

If seeds are kept dry, they show no signs of life, but when they have water, air, and suitable warmth, they begin to grow and the seed is said to germinate.*

THE GERMINATION OF BEAN SEEDS

When a seed germinates in the soil we cannot see what happens unless we dig up the seeds from time to time. But if we use

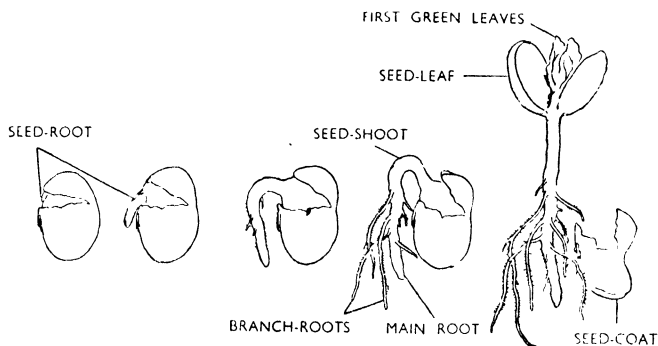


FIG. 24. GERMINATION OF BEAN

glass vessels, lined with blotting-paper and filled with damp sand or sawdust, putting the seeds between the glass and the blotting-paper, we can see all the changes that take place without interfering with the growth of the seeds.

When we plant soaked bean seeds in this way, we see that the seed-coat first splits near the tiny hole opposite the end of the seed-scar. Then the seed-root comes out and grows *downwards*, whatever the original position of the seed. The seed-shoot grows more slowly and pushes itself out, shaped like a hook.

At first, the seedling feeds entirely on the food stored in the seed-leaves, so that these gradually become smaller and smaller. If the seed-leaves are cut off as soon as the seed-root and seed-shoot have begun to grow, the young plant dies for lack of food, because

it cannot yet make its own food. When the tiny leaves of the seed-shoot open and turn green, however, the young plant is able to make its own food and can manage to go on growing even if the seed-leaves are cut off at this stage.

Some kinds of beans push their seed-leaves up above the ground together with the seed-shoot, and both the seed-leaves and the tiny folded leaves turn green when they reach the light.

THE GERMINATION OF MAIZE GRAINS

In a germinating maize grain, the seed-root comes out first and grows downwards. Then the pointed seed-shoot breaks through, covered and protected with a white skin as it forces its way upwards through the soil. When it reaches the surface, the first green leaf breaks through the covering skin and unrolls itself. Other roots soon appear which are not branches of the main root (as in the bean) but which start from the seed itself at the bottom of the seed-shoot. After a few days, these roots become as long as the first root. As the seedling grows, the grain becomes softer and gets smaller and smaller as the food material is used up.

Watch the germination of other seeds, at home, for yourself.

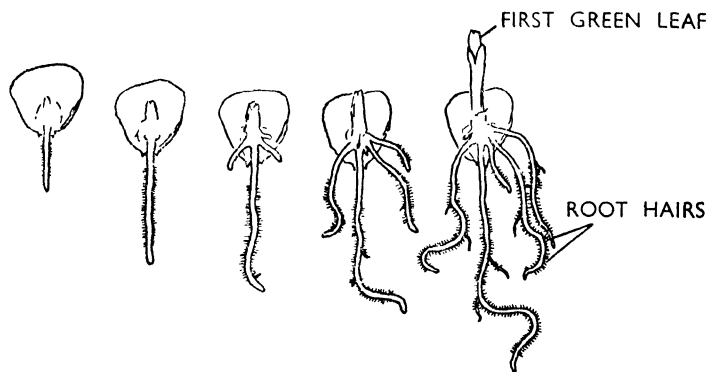


FIG. 25. GERMINATION OF MAIZE

THE TWO GREAT GROUPS OF FLOWERING PLANTS—MONO-COTYLEDONS AND DI-COTYLEDONS

If we examine the seeds and seedlings of many different kinds of flowering plants we find that they all contain a *seed-plant* and a store of food which is used up by the seedling as it grows, until it has set itself free from its seed-coat and has produced green leaves. Although every seed and seedling has to do the same sort of thing, they do not all do it in the same way. Some seeds have *only one seed-leaf*, e.g. maize, rice† (in fact, any ‘grain’), palms† and grasses. *These plants with only one seed-leaf are called mono-cotyledons.*† Such plants always have fibrous* roots, all growing from the bottom of the stem and all of about the same length and thickness, and they have leaves in which the veins run parallel* to one another. Other plants, whose seeds have *two seed-leaves*, are called *di-cotyledons*,† e.g. bean, pea,† squash,† sunflower.† Such plants usually have a *main root* from which grow smaller branch-roots, and their leaves have veins which form a network, i.e. they have *net-veined* leaves. All flowering plants fall into one of these two main groups.

THE CONDITIONS NECESSARY FOR GERMINATION

For a seed to germinate, **(a) water must be present, (b) air must be present, and (c) there must be suitable warmth**, i.e. the temperature must be neither too hot nor too cold. There is no difficulty about (c) in tropical countries, where the temperature is nearly always suitable for germination. We can show that these three conditions are necessary by the following simple experiments.

To show that water is necessary for germination.—Put a few dry seeds on cotton-wool in two test-tubes ‘A’ and ‘B’, the cotton-wool being *dry* in ‘A’ and *wet* in ‘B’. Keep both tubes in a warm room so that the seeds in ‘A’ have air and warmth, but *no water*, while those in ‘B’ have air, warmth *and water*.

What happens after a few days in a warm room?

.

What does the experiment show ?.....

To show that air is necessary for germination.—Put a few similar seeds in a test-tube ‘C’ containing *air-free water* (prepared by boiling some water to drive out the dissolved air, and then cooling it under a layer of oil to stop air entering again). Keep

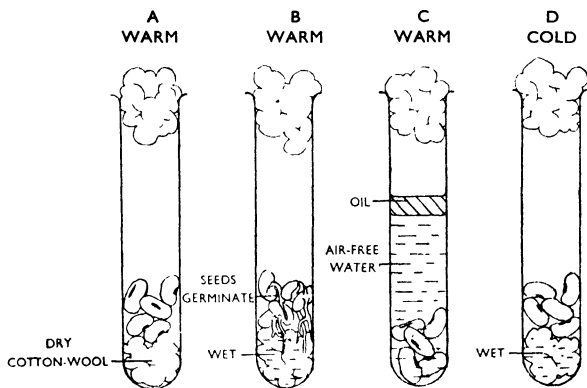


FIG. 26. EXPERIMENT SHOWING CONDITIONS FOR GERMINATION

- A. With air and warmth without water.
- B. With air and water and warmth.
- C. With water and warmth without air.
- D. With air and water without warmth (in ice-box).

this tube ‘C’ with tubes ‘A’ and ‘B’ in a warm room, so that the seeds in ‘C’ have water and warmth, but *no air*, while those in ‘B’ have water, warmth, *and air*. Compare ‘B’ and ‘C’ after a few days.

What do you see ?.....

What does this show ?.....

To show that suitable warmth is necessary for germination.—Put a few similar seeds on wet cotton-wool in a test-tube ‘D’, and keep the tube in an ice-box (or a moderately-cold refrigerator*) for a week, so that the seeds in ‘D’ have water and air, but *little*

warmth, while those in 'B' have water, air *and more warmth*. Compare 'B' and 'D' after a week.

What do you see ?.....

What does this show ?.....

GROWTH

THE GROWING REGION OF A ROOT

We have seen that the seed-root always grows downwards into the soil, pushing its way through the soil as it grows in length. We shall now find just where this growth in length takes place. Let some seeds germinate in a roll of damp cloth and then pick out a seedling with a straight seed-root. Starting at the tip of the root, mark off equal spaces of 1 mm. with Indian ink (using a piece of thread stretched across the points of a pair of forceps*).

Now put the seedling between the glass and the damp blotting-paper of a germination-vessel and look at it every few hours.

What do you notice as the root grows ?.....

Which marks become wider apart ?.....

Hence, *all the growth in length of a root takes place close behind the root-tip*, as shown in the diagram. This, of course, is the best place for the root to apply its pushing force, just where it is needed to force the root-tip through the soil.

(If you wanted to push a long, thin stick into the soil, where would you hold it ?.....

.....

.....

.....)

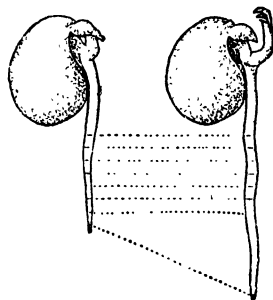
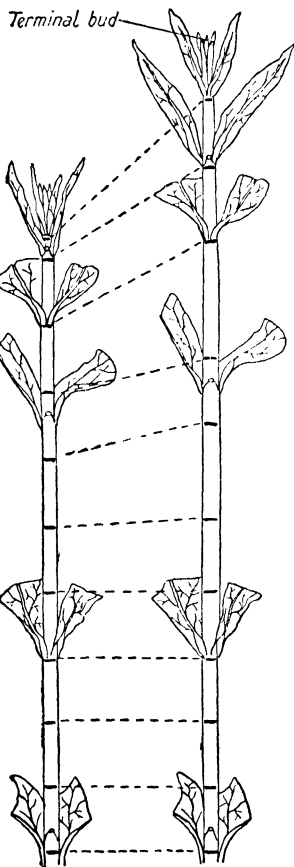


FIG. 27

THE GROWING REGION OF A STEM

We can find out where growth takes place in the stem in the same way. Mark off the main stem of a growing seedling with Indian ink, putting the marks 5 mm. apart, and look at it every few hours.



What do you notice as the stem grows ?

Which marks have become wider apart ?

Hence, *growth in stems is spread over a considerable length of the young stem*, as shown in the diagram, and is not limited to a very short region just behind the tip, as in roots. The stem, unlike the root, does not have to overcome any resistance as it grows in length through the air, so there is no need for its growth to be limited to one small region.

THE ROOT-CAP

As the tip of the root is pushed through the soil, the outer layer gets worn away. If an undamaged root-tip is examined with a lens, we find that the root-tip is protected by a *root-cap*,† usually less than 1 mm. long. The root-tips of many water-plants and the air-roots of Orchids† show well-marked root-caps because they are not worn away by being pushed through the soil. Roots growing in soil usually have their root-caps rubbed smooth, and they can only be seen by cutting

FIG. 28.
GROWING REGION OF STEM

a very thin slice* from the tip of the root and examining it under a microscope. As the root forces its way through the soil, the outside is worn away, but it is always being renewed from the *growing-point* inside, just behind the root-tip. Growing roots can exert* a considerable force, e.g. brick walls and concrete drains* are often cracked by the roots of neighbouring trees.

THE DIRECTION OF GROWTH IN ROOTS AND STEMS

We have seen that in whatever position the seed is planted, the main root always grows downwards and the main stem always grows upwards. In each case the direction of growth is the result of the *force of gravity*,† i.e. the pull of the Earth.

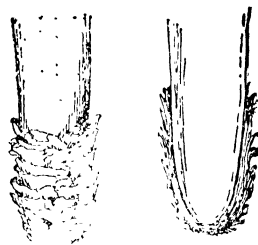


FIG. 29. ROOT-CAP OF SCREW PINE

TO SHOW THE EFFECT OF GRAVITY ON THE DIRECTION OF GROWTH OF THE ROOT

Let some seeds (e.g. Cow-peas†) germinate in a roll of damp cloth, and then pick out a seedling with a nearly straight root and stem. Pin it to the cork of a bottle or large test-tube lined with damp blotting-paper so that it is horizontal, as shown in the diagram. Put the vessel in a dark place and look at it every hour.

Which part of the root turns down ?.....

In this experiment, the root gets no light, so it cannot be said that it is merely turning away from the light. Also, since the vessel is lined on all sides with damp blotting-paper, it cannot be said that the root is merely turning towards water. The only force

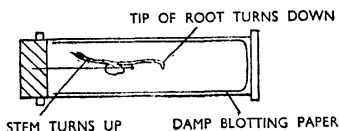


FIG. 30. EFFECT OF GRAVITY ON DIRECTION OF GROWTH

which has acted on the root from below is the force of *gravity*.

TO SHOW THE EFFECT OF GRAVITY ON THE DIRECTION OF GROWTH OF THE STEM

In the last experiment, it is also seen that the main stem turns upwards so as to bring itself into a more upright position. It is also seen that the region in which the stem begins to bend upwards is some distance behind the tip. In fact, it is the same region as that in which the stem grows in length. (Just as the growing-point of the root is the region which answers to the force of gravity.) As the seedling was kept in the dark and was equally damp on all sides, the stem must be growing upwards because of gravity. Hence, **the force of gravity directs the growth of the stem upwards and the growth of the root downwards.**

TO SHOW THE EFFECT OF LIGHT ON THE DIRECTION OF GROWTH

We have all noticed that when plants are kept in a room near a window they bend their main stems towards the window and spread out their leaves to the light. This effect of light on the direction of growth can be shown very clearly by the following experiment:—A piece of coarse cloth is stretched across the mouth of a glass vessel and is kept damp by hanging one end of

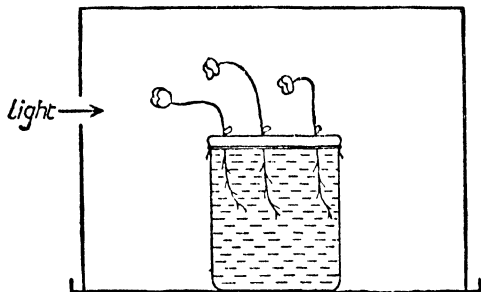


FIG. 31. EFFECT OF LIGHT ON DIRECTION OF GROWTH

the cloth in the water inside the vessel. Small seeds (e.g. Cow-pea or Cress†) are put on the damp cloth, and the vessel is put inside a light-tight box provided with a small hole in one of its sides, as shown in the diagram. When the seeds germinate, it is

seen that the main stems grow straight towards the hole, i.e. **the stems bend towards the light**, while the roots grow in the opposite direction, i.e. **exposed roots bend away from the light**. The green leaves grow at right-angles to the direction of the rays of light, so as to receive as much light as possible.

THE EFFECT OF EXPOSURE TO LIGHT ON PLANT GROWTH IN GENERAL

A few seeds (e.g. Sword-bean† or Cow-pea) are planted in damp soil in two similar pots. One pot is put inside a dark cupboard and the other is kept outside. After about a week, when we compare the seedlings which have grown in the light with those grown in the dark, we see some striking differences.

(i) There is a very big difference in *colour*. The seedlings grown in the dark are *white* or *yellow*, while those grown in the light are *green*. Hence, *the green colour of plants is only formed in daylight*. If the white seedlings are taken out of the dark they begin to turn green after a few hours in the light.

(ii) There is also a big difference between the sizes of the leaves of seedlings grown in the dark and of those grown in the light. The seedlings grown in the dark

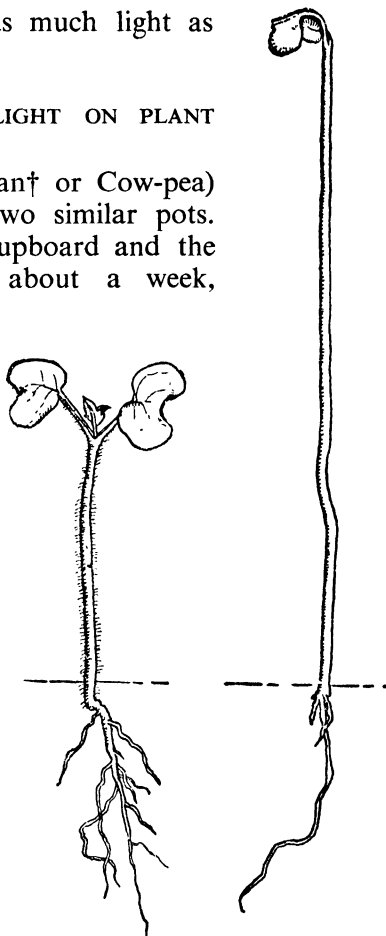


FIG. 32. EFFECT OF LIGHT ON GROWTH

have only a few very small yellow leaves which often stay folded up, while the seedlings grown in the light have much larger green leaves which are well spread out.

It is easy to see why there should be such big differences between plants grown in the dark and those grown in the light. When in the dark, a plant grows a long, thin stem so as to reach light as quickly as possible. Also, leaves are of no use to the plant unless they are in the light, so a plant growing in the dark does not grow leaves, which would be useless. Once the stem has reached the light, the leaves begin to grow rapidly and they soon turn green.

The direction of growth of leaves is also affected by the light, and they usually grow so that the light falls on their upper surface. For example, if a plant is kept in a room, near a window, the leaves soon turn so as to put themselves at right-angles to the direction of the rays of light. **The main need of a green leaf is to get enough light.**

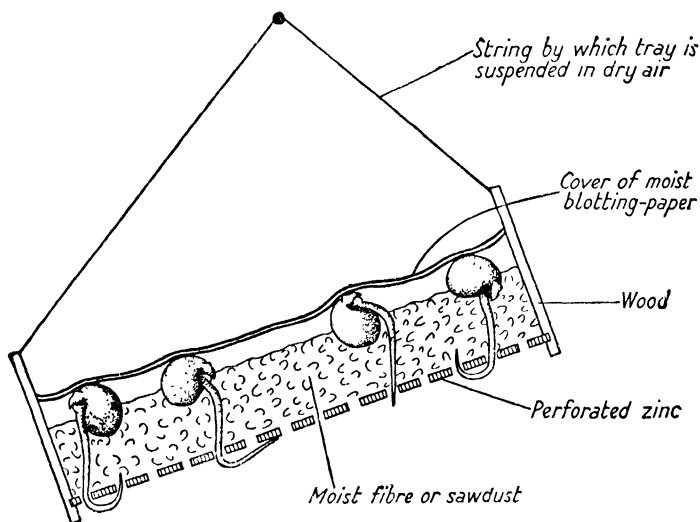


FIG. 33. ROOTS GROW TOWARDS WATER

THE EFFECT OF WATER ON THE DIRECTION OF GROWTH OF ROOTS

The roots of a plant are always attracted by water. This attraction can be shown by the following experiment:—Small seeds are sown in damp sand or sawdust over a wire gauze which is fixed at an angle, the whole being covered with a large jar or tin so that the air inside is kept damp. When the seeds germinate, their roots grow downwards through the holes in the wire gauze, because of gravity, and they go on growing downwards as long as the surrounding air is damp. If the cover is now raised so as to let in drier air, the roots are attracted more strongly by the water above the wire gauze, and they bend back again to the bottom of the gauze, as shown in the diagram. This experiment shows clearly that **the effect of water on the direction of growth of the root is greater than that of gravity.** (The first need of any root, of course, is to get enough *water*.)

ROOTS

The main work of the root is

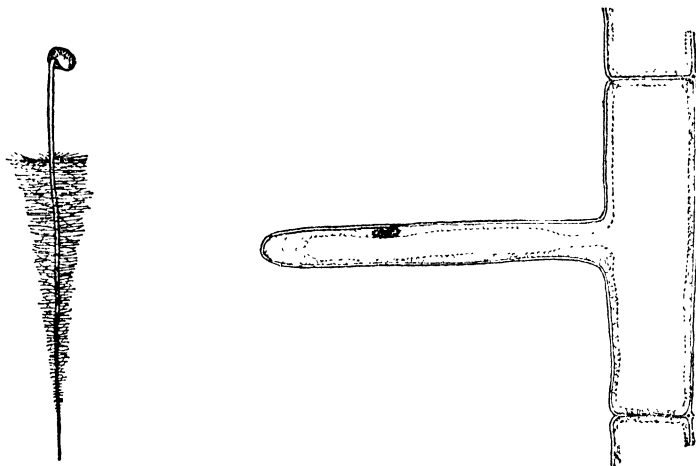
(i) *to take in water containing dissolved mineral matter from the soil*, and

(ii) *to hold the plant firmly in the ground.* We have seen that the seed-root is always the first part of the seed-plant to come out from the seed, and it is clearly most important that the root should get to work as soon as possible so that it may supply the young plant with water. (It already has a supply of *food* in its seed-leaves.) We know that if we cut off a stem or branch and put the cut end in water, it will live for a few days, but it is only the roots which can supply the plant with water for a long time. We shall now learn how roots take in water.

THE ABSORPTION* OF WATER BY ROOTS

Plants produce large numbers of branch-roots and still smaller rootlets which spread out in every direction through the soil in their search for water. A little way behind the tips of all these

fine rootlets are found large numbers of very fine hairs, called *root-hairs*. (We can see these root-hairs most easily on seedlings which have been grown on damp blotting-paper or in a roll of damp cloth.) When seedlings are uprooted from the soil, nearly all the root-hairs are torn off. These root-hairs are extremely important since they are almost *the only part of the root which can take in water and dissolved substances from the soil*. When plants are transplanted* great care must be taken not to break the rootlets which bear the root-hairs. As much soil as possible



SEEDLING WITH ROOT-HAIRS

SINGLE ROOT-HAIR

(Greatly enlarged)

FIG. 34

must be kept round the roots, for if the root-hairs are damaged the plant will suffer because the older parts of the roots cannot take in water.

There are no root-hairs for about 1 cm. back from the root-tip. Then, for a distance of a few centimetres, they are found in great numbers. On the older parts of the root there are no root-hairs. Notice that they grow *just behind the growing-point*, where they will not be torn off as the root grows in length. Under the

microscope, each root-hair is seen to be a narrow tube, closed at the end, and the root-hairs cling* very closely to the grains of soil because, in damp soil, every soil-particle is covered with a thin film of water, and the root-hairs must touch this film of water if they are to absorb it. The outside of the root-hair is sticky, so that it 'glues'* itself to the grains of soil. Hence, if we uproot a seedling and wash off the soil from its root under the tap, we cannot remove the soil without tearing off the root-hairs at the same time. Root-hairs live for a short time only, then they die and new ones grow out, nearer the root-tip, to take their place.



FIG. 35. ROOT-HAIRS CLINGING TO PARTICLES OF SOIL

Only water and dissolved substances can enter the root: solid particles, however small, cannot enter. This can be shown by the following experiment:—Take two jars of water and colour one of them with a little red ink, which is a red dye *dissolved* in water. Colour the other one red with carmine,† an *insoluble* colouring matter which remains *suspended* in the water as very fine solid particles. Dig up two white-flowered Balsam plants, damaging their roots as little as possible, and put one of them in each jar. Next day, the plant in the red ink *solution* is found to be stained with red inside the root and stem, while the white flowers are also red round their edges. The plant in the carmine *suspension*, however, shows no trace of red in its root, stem or flowers. This experiment shows, therefore, that *only dissolved substances can enter the root: solid particles, however small, cannot enter.*

We must now find out how water and dissolved substances enter the root-hairs although they are tiny closed tubes without any holes in their walls.

OSMOSIS AND OSMOTIC PRESSURE

Water and dissolved substances enter the root-hairs by a physical process called osmosis.† In this process, if a strong

solution is put on one side of a thin skin, and a weak solution is put on the other side, the two solutions gradually become of the same strength. The following experiment shows what happens in this process:—

A piece of skin is tied tightly over the wide end of a thistle-funnel and the wide part of the funnel is then filled with a strong solution of sugar. (Bladder,† ‘cellophane’,† or parchment-paper† may be used; old drum-heads of sheep-skin are excellent.

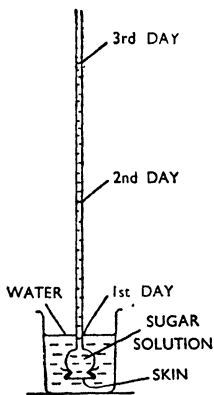
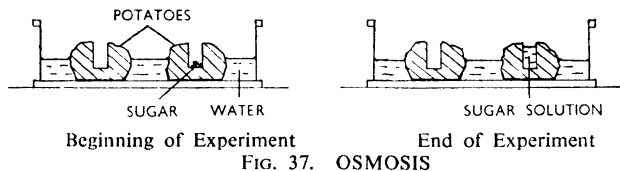


FIG. 36. OSMOSIS

Many other soluble substances can be used instead of sugar.) The thistle-funnel is supported in a beaker of water as shown in the diagram, and the level of the sugar solution inside the thistle-funnel is marked with a strip of gummed paper. In a short time the level of the sugar solution begins to rise and goes on rising, day by day, until the pressure exerted by the column* of water in the tube becomes heavy enough to burst the skin. By using long glass tubes joined to the thistle-funnel, it is easy to get a rise of over ten feet. The height of this column of water measures the osmotic pressure† of the sugar solution.

This osmotic pressure is caused by water passing from the weak solution in the beaker through the skin into the strong sugar solution. (A little sugar passes in the opposite direction at the same time.) Root-hairs take in water from the soil in just the same way, since the sap,† or liquid inside the root-hairs, is a stronger solution than the soil-water outside. Hence, **water enters the root-hairs by osmosis.** If the soil-water contains too much dissolved matter, osmosis may take place in the opposite direction, and water passes outwards from the root-hairs, thus making the plant ‘wilt’,* (i.e. the green parts of the plant become soft and hang down). In the above experiment, the thistle-funnel and skin, containing sugar solution, form a big ‘working model’ of a root-hair, and the water in the beaker represents the soil-water.

Another simple experiment will show that osmosis takes place in living plant material. Take two similar English potatoes† and cut off a slice from one end of each so as to form a flat base for it to stand on. Remove a ring of skin (about 1 in. wide) round

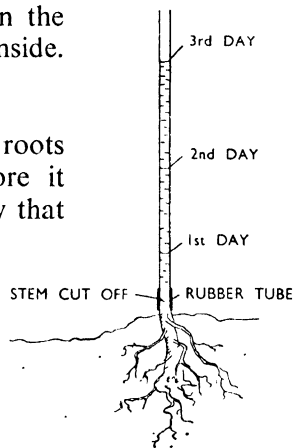


the base of each potato, and then make a round hole in the top of each, down to about an inch from the base, as shown in the diagram. (Make the hole with a large cork-borer.*) Stand the potatoes in a dish containing a little water; put a few grams of sugar in the hole of one potato, and leave the hole in the other potato empty.

In a short time the sugar absorbs enough water to form a solution, and the volume of this solution gradually increases as water enters by osmosis through the potato. In the other potato, no liquid collects in the hole because there is no strong solution inside.

ROOT PRESSURE

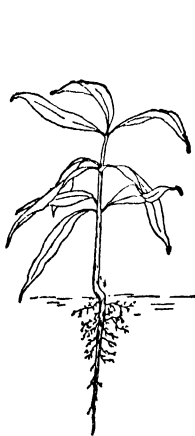
In tall trees, the water taken in by the roots has to be raised to a great height before it reaches the topmost leaves, and we know that some force is required to raise anything to a height. *Part* of the force required to raise this water is supplied by the root, which is not only able to take in water through the root-hairs, but can also force the water up into the stem. We can show this *root pressure* by the



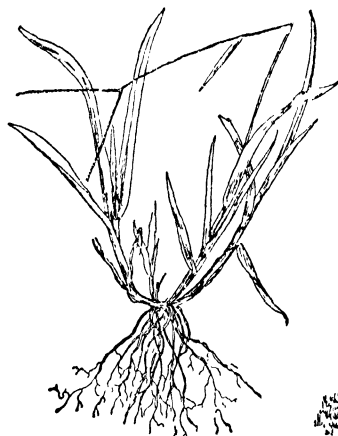
following experiment:—Cut through the stem of a healthy Balsam plant just above the soil, and *at once* fit a straight glass tube to it with thick rubber tube, as shown in the diagram. Pour a little water into the glass tube so as to keep the cut end of the stem wet at the beginning of the experiment, and mark the level of the water inside the tube with a rubber band or with a strip of gummed paper. The water-level in the glass tube soon begins to rise and goes on rising for several days if the plant is kept well watered. If the level is marked every hour, it is found that the level sometimes rises quickly and sometimes slowly, showing that the root pressure is not always the same. We see, therefore, that the root acts as a ‘pumping-station’, taking in water through its root-hairs by osmosis and then forcing it up the stem. In later lessons we shall learn how this upward flow of water continues as far as the leaves.

OTHER WORK OF ROOTS

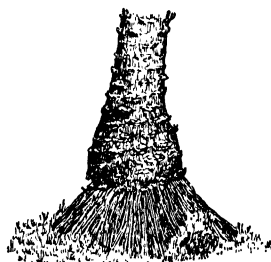
Besides taking in water containing dissolved mineral matter from the soil, roots also hold the plant firmly in the ground, or,



TAP-ROOT
MANGO SEEDLING



FIBROUS-ROOTS
GRASS



FIBROUS-ROOTS
PALM

FIG. 39

in the case of some *climbing plants* (e.g. Vanilla† and some other Orchids), to other supports. We have seen that the roots branch and spread in all directions through the soil in their search for water, and that this branching and spreading also serves to hold the plant firmly in the soil.

TAP-ROOTS AND FIBROUS-ROOTS

The roots of the plants we have studied have been of two kinds. In *di-cotyledons* (e.g. Cow-pea, Mango,† Cotton,† Orange,† Lime†) the first root to appear grows straight downwards and is much bigger than the branch-roots which appear later. A main root of this kind is called a *tap-root*,† and this is characteristic of plants whose seeds have *two* seed-leaves.

In *mono-cotyledons* (e.g. Maize, Rice, Millet,† Bamboo† and all palms and grasses) all the roots are quite thin and of about the same size. Such roots are called *fibrous-roots*,† and they usually grow only in the top layer of the soil, whereas tap-roots make their way deep down into the soil.

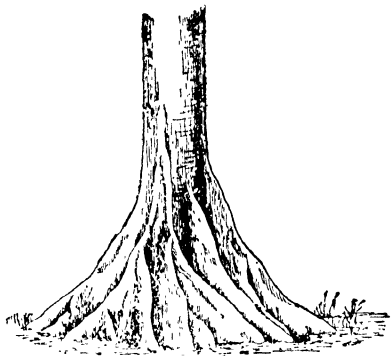


FIG. 40.
BUTTRESS-ROOTS—SILK-COTTON

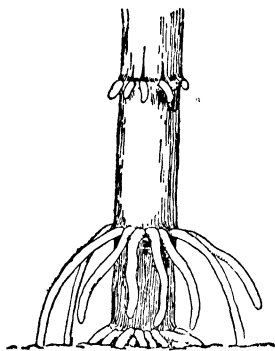
ROOTS WHICH GROW ABOVE THE GROUND

Most roots start from the bottom of the stem and grow down through the soil, but some plants send out roots *above* the ground. For example, some plants form *buttress-roots*,† which are partly stems and partly roots, to support their main stems more firmly. Plants with buttress-roots are Ceiba† (Silk-Cotton†.....),¹ Poinciana† (Flame Tree†.....), Ficus elastica†

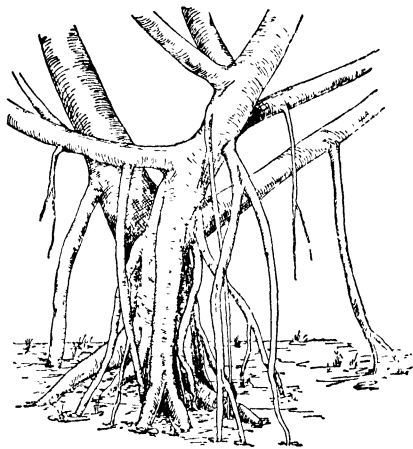
¹ Write in the local name.

(Indian Rubber-tree†—*not* Para Rubber),
Terminalia† (Indian Almond†.....). These
 buttress-roots are usually produced by trees whose roots do not
 go deep down into the ground.

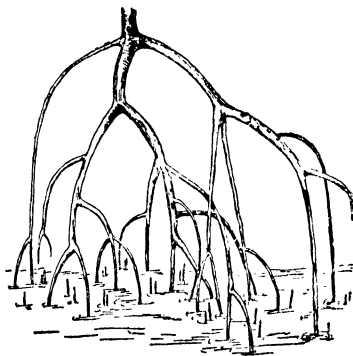
Maize sends out *prop-roots*† from its stem, a little way above
 the surface of the soil. Screw-Pine† (.....) has similar



MAIZE



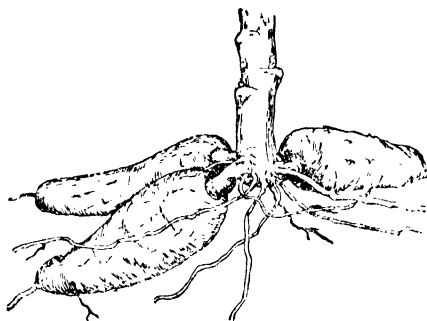
BANYAN



RED MANGROVE

FIG. 41. PROP-ROOTS

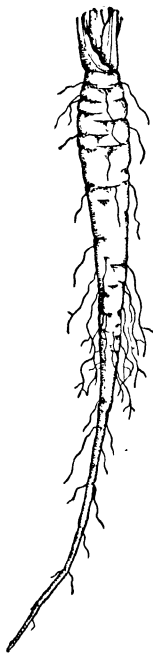
prop-roots growing from its stem, while the Banyan† (.....) sends down roots from its branches, and these roots grow into the soil and then support the branches.



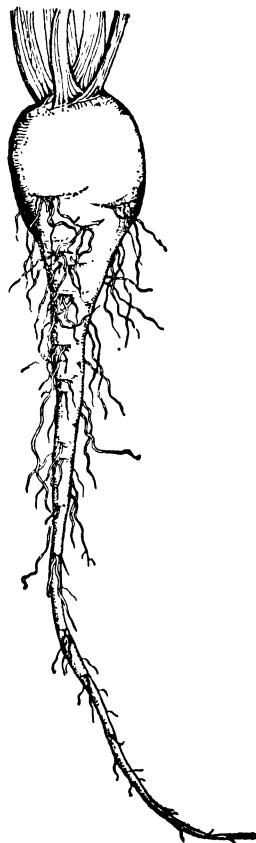
CASSAVA

Mangrove† (.....), which grows along river-banks and sea-shores, sends down prop-roots into the mud to support its stems and branches. Mangrove, too, sends *breathing-roots*† upwards out of the mud to get air for the parts which are under water.

Some Orchids that grow high up on trees in tropical forests have long, hanging *air-roots*† which absorb the rain that falls on them. We shall refer to the use of roots for climbing later.



CARROT



BEETROOT

FIG. 42. STORAGE-ROOTS

STORAGE ROOTS†

Some plants use their roots for storing reserves of food material. The roots of Tapioca† (Cassava†.....), Carrot† (.....), Beetroot† (.....), Turnip† (.....) and Radish† (.....) are very much swollen, and they contain large quantities of food material, usually *starch*, but sometimes *sugar*. These reserves of food, of course, are often used by Man and other animals for their own food: in fact, it is very lucky for animals that plants nearly always make more food than they use themselves.

STEMS

The main uses of stems are

(a) *to hold the leaves in the best position for receiving light* (and, sometimes, to display the flowers),

(b) *to carry water, containing dissolved mineral matter, from the root up to the leaves, and*

(c) *to carry manufactured food downwards from the leaves to other parts of the plant.*

The stems of different plants are of many different kinds, sizes and shapes. Most plants, e.g. trees, have an *upright stem* to hold their leaves above the surrounding plants so that they will not be shaded. In forest and jungle* there is very fierce competition for *light*, each tree trying to grow higher than the others.

A plant is usually surrounded by its food materials—air containing a little carbon dioxide surrounds its leaves, and the soil around its roots contains water and mineral salts. In later lessons you will see that, in spite of this, it often has to struggle to get enough light.

If an upright stem is to grow tall it must be strong, but many plants which have only weak, thin stems can raise their leaves to the light by taking hold of stronger plant stems or other supports. Such plants are called *climbing plants*, and the commonest ways

in which weak stems climb are (a) by twining,* (b) by tendrils,† (c) by thorns† and hooks, and (d) by roots.

CLIMBING BY TWINING

Plants like Morning Glory† (.....), Yam† (.....), and many kinds of Beans, twist their stems round other plants or supports and climb in this way.

The tip of the young stem first bends to one side and then begins to swing slowly round in a circle until it touches something solid. The growing part of the

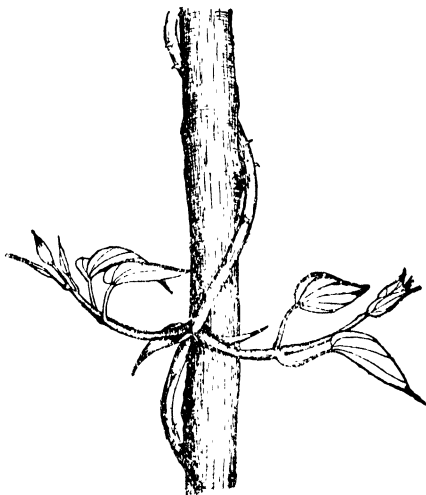


FIG. 43.
TWINING STEM—YAM

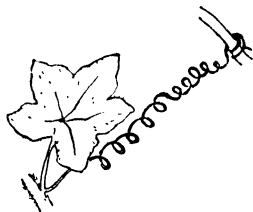


FIG. 44.
CUCUMBER TENDRIL

stem then twists round and round, clinging tightly to the support.

CLIMBING BY TENDRILS

Many plants grow tendrils for clinging to supports, e.g. Squash (Pumpkin†.....), Cucumert† (.....), Melon† (.....), Antigonon† (Honolulu.....), Gloriosa† (Climbing Lily†.....), and Passion Flower† (.....). Branch-stems, leaf-stalks, and sometimes leaf-tips, grow into long, thin tendrils which swing slowly round

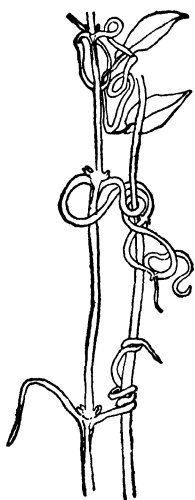


FIG. 45.
CLEMATIS

and round until they touch a support. The end of the tendril then twists itself round the support. The rest of the tendril then twists to form a spring which stretches when the plant is blown by the wind. In *Gloriosa*, the leaf-tips form tendrils. In *Clematis*† (.....) the leaf-stalks twist round the support.

CLIMBING BY THORNS AND HOOKS

Some plants help themselves to climb by growing thorns or hooks which point backwards down the stem, e.g. *Rattan*† (.....), *Mimosa*† (*Sensitive Plant*†), *Lantana*† (.....), and *Bougainvillea*† (.....). As the stem grows upwards, these backward-pointing hooks slide forward and catch on supports so that the stem cannot slip back again. This is a more chancy method of climbing than by twining or by tendrils, and these plants may be called ‘scramblers’* rather than ‘climbers’.



FIG. 46.
THORNS—RATTAN

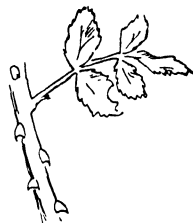


FIG. 47.
THORNS OF ROSE

CLIMBING BY ROOTS

Some climbing plants, e.g. *Vanilla* and some other Orchids, Pepper† (.....), send out *air-roots* from their stems, and these roots wrap themselves round the stems of other plants or fasten themselves in holes and cracks, thus enabling the plant to climb and get its leaves to the light. Climbing plants with



FIG. 48.
CLASPING-ROOTS—PEPPER

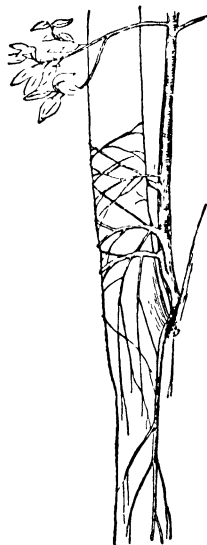


FIG. 49.
CLASPING-ROOTS

clasp^{*}ing-roots are often seen on the trunks of trees in tropical forests. Some root-climbers go even farther and get food as well as support from other plants, e.g. *Loranthus*† (*Mistletoe*†.....), *Cuscuta*† (*Dodder*†.....), and *Cassytha*† (.....). Such plants are called parasites.†

CREEPING STEMS

The stems of some plants, e.g. many grasses, neither grow upright nor climb up supports, but simply lie on the ground. They can only do this where they are not shaded by other plants, hence plants with *creeping stems* are commonest on open waste land and on the sea-shore. Some of these creeping plants produce new plants at intervals,* so that a number of plants may be joined together by horizontal stems, or *runners*.† Sweet Potato† (.....), Carpet Grass† (.....), Spinifex† (.....), and Hydrocotyle† (.....)



FIG. 50. CREEPING STEMS—SWEET POTATO WITH TUBERS

have creeping stems of this kind. If the connecting runner is cut or broken, the new plants can live independently. Plants with creeping stems are often used as *cover-crops* since they form a deep mass of stems and leaves completely covering the soil, e.g. Centrosema† (.....) and Calopogonium† (.....). We shall learn more about cover-crops later.

Many creeping stems, however, only lie on the ground if they can find nothing up which to climb, e.g. plants of the Sweet Potato and Squash families, Centrosema and Calopogonium will climb if they can find any support, otherwise they creep along the ground.

UNDERGROUND STEMS

Some plants have stems which grow below the surface of the soil and which look very much like roots. To tell an *underground stem* from a true *root*, you must remember that a stem bears *leaves* and *buds* of some kind while roots do not. In most cases, however, the leaves on underground stems are very small, just tiny scales, being white, yellow or brown in colour.

Most underground stems store up plant food, usually *starch*, but sometimes *sugar*, and many plants can be grown from a piece of underground stem more easily than from seeds. This is called vegetative* reproduction, but we shall study reproduction in detail later.

Underground stems can be divided into several different classes:—(a) bulbs,† (b) corms,† (c) rootstocks† (or rhizomes†), (d) tubers,† and (e) suckers.†

BULBS

Common examples of bulbs are Onions† (.....), Lilies† (.....) and Crinum† (.....). A bulb is simply a big *underground bud*, consisting of a short stem covered with thick, fleshy scale-leaves full of food-material. The roots all grow from the bottom of the bulb and the new plant grows from the middle of the bulb. When a bulb is planted, it produces a new plant much more quickly than when a seed is planted, since the bulb contains so much food.

If a Lily bulb is planted in

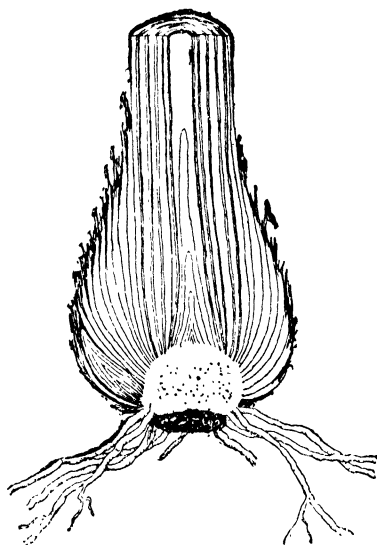


FIG. 51. SECTION OF BULB OF CRINUM LILY

damp soil, the first thing to appear above the ground is the flower-stalk, followed later by leaves. When all the food in the bulb has been used up, the green leaves manufacture more food which is stored up in a new bulb which can survive* a dry or cold season and then start growing once more.

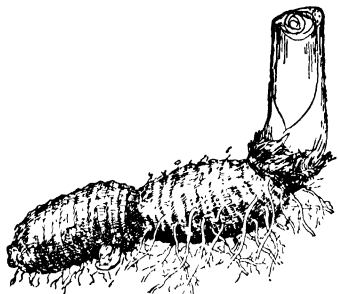


FIG. 52. UNDERGROUND STEM—
COCO-YAM

CORMS

From the outside, corms often look like bulbs, but when they are cut open, corms are seen to be solid instead of being built up of overlapping* scale-leaves. Buds grow round the top and sides of the old corm and develop into new corms which can be used to produce

new plants. Plants which reproduce themselves by corms are *Gloriosa*, *Colocasia*† (*Coco-yam*†.....) and *Xanthostoma*† (*Tania*†.....).

ROOTSTOCKS

Examples of plants with rootstocks (or rhizomes) are *Arrowroot*† (.....), *Ginger*† (.....), *Canna*† (.....), *Water Lily*† (.....), *Ferns*† (.....) and *Imperata*† (*Lalang*†.....). These plants have thickened underground stems running almost horizontally below the surface of the soil and bearing scale-leaves, buds and roots. The buds on these underground

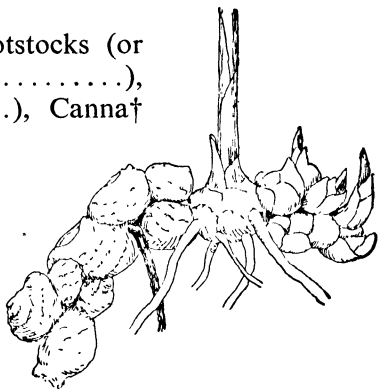


FIG. 53. UNDERGROUND STEM
(RHIZOME) OF GINGER

stems form shoots which grow above the ground and bear leaves and flowers. It is easier to grow such plants from a piece of the rootstock than from seeds: in fact, many troublesome *weeds* (i.e. 'plants growing in the wrong place') owe their success to having a rootstock. A good example is *Imperata* (Lalang), which is one of the first weeds to appear on freshly-cleared soil (because its seeds are easily carried by the wind). It soon produces rootstocks running underground in all directions and stores up reserve food in them. If there is a fire or dry season, most of the other plants are killed, but the underground stems of weeds like Lalang are undamaged and fresh shoots soon appear above-ground. Such weeds are very difficult to get rid of. One way is to dig the soil and pick out *every bit* of underground stem. Another way is to cut the grass at frequent intervals, before it has time to store food in its underground stem. When all its reserve food is used up, the plant dies. Since the leaves of Lalang stand upright, it can be got rid of by frequent mowing* without harming other kinds of grass whose leaves lie almost flat on the ground. Mowing removes *all* the upright Lalang leaves and stops the plant from making food, but the leaves of more desirable grasses, lying flat on the ground, escape.

TUBERS

A tuber is a much thickened part of an underground stem in which a plant stores up food. Good examples of tubers are English Potatoes, Sweet Potatoes, and some Yams (.....). There do not seem to be any leaves on a potato, but we can see tiny buds which are called the 'eyes' of the potato, with the scar left by a scale-leaf as the 'eyebrow'.* If a tuber is planted in damp soil, the 'eyes' send out roots and shoots which form new plants. English potatoes are nearly always grown from tubers in this way; a

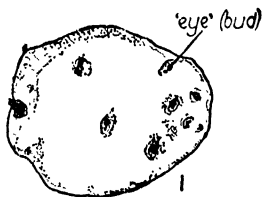


FIG. 54.
POTATO TUBER

piece of potato bearing an 'eye' is planted instead of using seeds.

SUCKERS

A sucker is a thick, fleshy shoot growing from beneath the soil, either from the base of the stem or from the root. Good examples of plants which form suckers are Bananas† (.....)

and Plantains† (.....).

Bananas are always grown from *root-suckers* since they never produce fertile seeds.

Pineapples† (.....)

produce *stem-suckers* from the base of the stem and these suckers can be removed and planted to produce new plants. Suckers are sometimes called *off-shoots*.

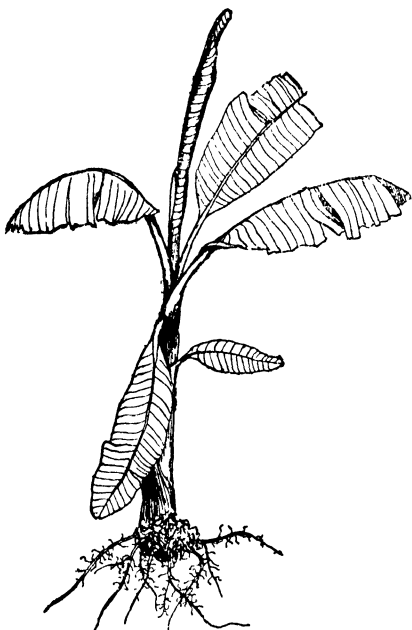


FIG. 55. COMPLETE SUCKER OF BANANA PLANT

Although it is convenient to classify underground stems in this way, it is often difficult to make sharp distinctions, e.g. it is sometimes hard to decide whether an underground part is a corm, or a tuber, or even a storage root. In this Science Course, we shall concern ourselves with main principles rather than with fine distinctions.

QUESTIONS

1. What is the first part of the young plant to come out of the seed during germination ?

2. What is the use of flowers to a plant ?
3. Why do we call the English potato an ' underground stem ' ?
4. In what part of the root does growth in length take place ?
5. What are the conditions necessary for the germination of seeds ?
6. What striking differences have you noticed between a plant grown in the light and another plant of the same kind grown in the dark ?
7. Give two examples of plants which have *fibrous roots*.
8. What causes roots to grow downwards ?
9. What is the main use of roots to the plant ?
10. Name a plant which climbs by thorns or hooks.
11. What is the main use of leaves to a plant ?
12. Give an example of a plant which stores food in a *bulb*.
13. A plant which gets all its food from another plant is called a
14. Name two common plants which climb by tendrils.
15. What kind of roots are produced by plants having only one seed-leaf ?
16. Two solutions of different strength, when separated by a skin, gradually mix. What process is this ?
17. What is the use of seed-leaves to a germinating bean ?

CHAPTER V

WATER

Now that we know something about *air*, the commonest substance in the world, we will turn to the second commonest substance—water.† A map of the world shows that about three-quarters of the Earth's surface is covered by seas, lakes and rivers. The atmosphere also contains a lot of water-vapour. Many rocks are crystalline and contain much water of crystallization. Animals and plants, too, contain a large proportion of water, e.g. about 70 per cent. of our own body-weight is water. Water is necessary for life: men have lived for more than a month without food, but they had to drink plenty of water to keep alive.

NATURAL WATERS

Water, as it is found in Nature, always contains dissolved matter and usually some suspended matter. Since water from different sources contains different kinds of foreign matter, it is convenient to classify natural waters under the following headings: (a) *Rain-water*, (b) *Spring-water* (or *deep well-water*), (c) *River-water* and (d) *Sea-water*.

RAIN-WATER

Rain, as it begins to fall from the clouds, is almost pure water, but as it falls it dissolves some air and it also carries down any dust (living and non-living) that may be in the air. In other words, rain washes the air, so that rain-water collected at the beginning of a shower contains much more foreign matter than rain-water collected towards the end of a shower. We can show

that rain-water contains dissolved air by the experiment shown in the diagram. One vessel contains rain-water and the other contains recently-boiled water. The two vessels are put under a bell-jar connected to an air-pump. As the air is pumped out of the bell-jar, bubbles form in the rain-water and rise to the surface, but no bubbles are formed in the boiled ('air-free') water.

SPRING-WATER AND WELL-WATER

During heavy rain, some of the rain-water runs off the top as *surface-water*, carrying both dissolved and suspended matter to the rivers. Most of the rain, however, usually sinks into the earth, dissolving small quantities of *mineral matter* (or inorganic* matter) from the rocks and soil. This water sinks down in the earth until it comes to a non-porous* layer of clay or rock.

In hilly country, it will then reach the surface again as a *spring*. In flat country it may be raised to the surface from deep wells. In either case, the same kind of clear, sparkling* water is obtained. It contains *dissolved mineral matter*, but is almost free from suspended matter since it has been filtered in passing through the earth. This spring-water, or deep well-water, is usually good drinking-water. ✓

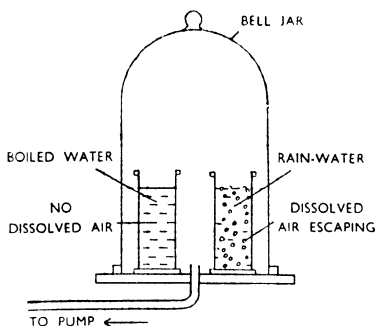


FIG. 56. DISSOLVED AIR IN RAIN-WATER

RIVER-WATER

Surface-water and spring-water both flow into rivers, hence river-water contains *both dissolved and suspended matter*. The amount of foreign matter gradually increases as the river flows along, especially if it receives drainage* from towns, villages and cultivated land on its banks. Just as spring- and surface-water flow into rivers, the rivers themselves flow into the sea, carrying

dissolved mineral matter and any suspended matter which has not settled to the bottom as the flow of the river becomes slower.

SEA-WATER

When rivers enter the sea, most of the remaining suspended matter falls to the bottom (often forming a 'bar' at the river-mouth), but the dissolved matter remains in the sea-water. Now, water is always evaporating from the surface of the sea, but the water-vapour which rises from the sea by evaporation is *pure water*, containing no dissolved matter. Hence, if the sea is always losing pure water by evaporation and is always receiving dissolved mineral matter from the rivers, then the seas of the world must become more and more 'salty'.

The average amount of dissolved mineral matter in sea-water is about 4 per cent., more than three-quarters of which is common salt, which gives sea-water its characteristic taste. The other 1 per cent. is composed mainly of compounds of magnesium and calcium. The amount of dissolved mineral matter increases most rapidly in land-locked seas and lakes where the sun is hot and where evaporation is rapid. For example, the Dead Sea in Palestine contains about 23 per cent. of dissolved substances; but the Baltic Sea, which has less evaporation owing to its colder climate and which is fed with fresh water by many large rivers, contains only about 0.5 per cent. of dissolved matter, i.e. only about one-fiftieth of the amount in the Dead Sea. In fact, the Dead Sea is like a huge evaporating-dish, because the salt crystallizes out round the shores as the water is evaporated by the sun.

TO EXAMINE SOME NATURAL WATERS

(i) Put a mark on a clean test-tube about 2 in. from the bottom. Fill it to this mark with rain-water, pour this water on to a clean watch-glass and heat it gently on a water-bath. When all the water has disappeared, dry the *bottom* of the watch-glass and hold it up to the light.

How much dissolved matter does rain-water contain ?.....

.....
(ii) Repeat the experiment with spring-water (or with deep well-water).

How much dissolved matter does it contain ?.....

.....
(iii) Repeat the experiment with the same quantity of filtered river-water.

(Why is it necessary to filter in this case ?.....

.....)
How much dissolved matter does river-water contain ?.....

.....
(iv) Repeat the experiment with the same quantity of sea-water.

How much dissolved matter does sea-water contain ?.....

.....
What is the purest natural water ?.....

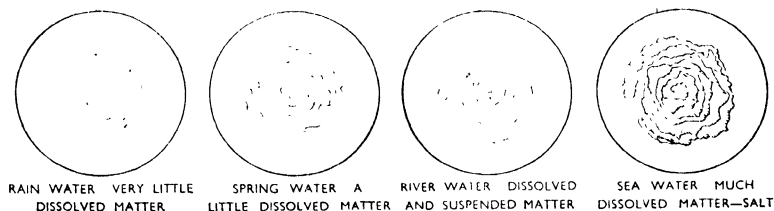


FIG. 57. RESIDUES FROM NATURAL WATERS

THE CIRCULATION OF WATER IN NATURE—THE WATER CYCLE

Water is always evaporating from the seas, lakes, and rivers (and also, we shall see later, from the surface of the soil and from the leaves of plants). Since water-vapour is very much lighter than dry air, damp air rises until it reaches a height at which it is cold enough for the water-vapour to condense to tiny drops of liquid water—so small that they float in the air—thus forming *clouds*. If more water condenses on these tiny drops they become big enough to fall as *rain* (or as *snow* in cold countries). This

rain-water either runs off as surface-water or it sinks into the ground and appears later as spring-water. In either case it is finally collected by rivers and carried to the sea, where it is evaporated once more, thus repeating the same *cycle* of changes.

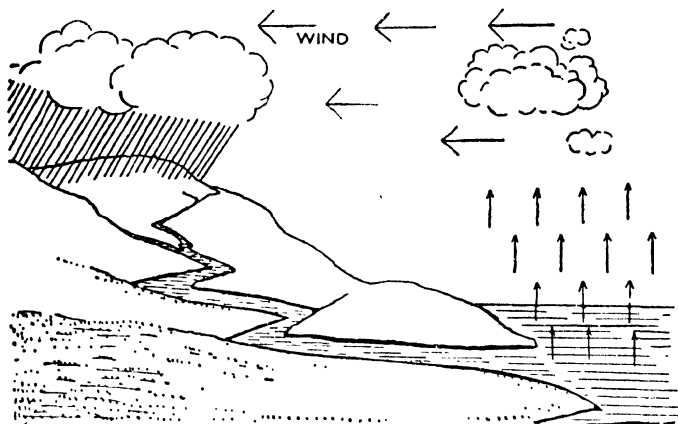


FIG. 58. THE SUN TAKES WATER FROM THE SEA, WHICH COMES BACK TO US AS RAIN

A *cycle* is a series* of changes which, in time, bring us back to the starting-point once more, just as a spinning bicycle-wheel brings the valve† back to the same point once in every complete turn. Our work at school, too, is arranged as a weekly cycle of lessons. We do different work on each day of the week, but each Monday we begin a new cycle and study the same subjects as we did the Monday before, in the same order.

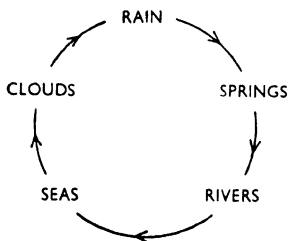


FIG. 59. THE WATER CYCLE

Since all the water in the world is always passing through a *cycle of changes*, as shown in the diagram, the total amount of water in the world never grows less. (Compare the Water Cycle with the Carbon Cycle, p. 61.)

DRINKING WATER

The dissolved mineral matter (or *inorganic* matter) in most natural waters is not bad for the health unless present in large quantities.

Most natural waters, however, also contain *suspended matter* which must be removed before the water is safe to drink. The most dangerous suspended impurities are *bacteria* (some of which cause disease), together with the remains of living things (organic* matter) on which the bacteria feed. This dangerous suspended organic matter may come from the soil and from sewage.* Although suspended clay and similar inorganic matter can often be seen, the suspended bacteria cannot be seen until the water is examined in the laboratory, by using a powerful microscope. Hence a sample of water may be perfectly clear to look at, and free from unpleasant taste or smell, and yet contain bacteria and organic matter on which they feed.

Most bacteria, however, are not harmful to man; some, we shall see later, are very useful. But since certain bacteria cause diseases like typhoid,† cholera† and dysentery,† **any water which is to be used for drinking must be free from bacteria, and free from organic matter on which bacteria might feed.** In addition to bacteria, natural waters in tropical countries often contain the eggs and young of tiny worms which cause disease if they enter the human body. Hence, nearly all natural waters need to be purified before they are used for drinking.

PURIFICATION OF WATER FOR DRINKING AND FOR HOUSEHOLD PURPOSES

(i) Small quantities of water can be made safe for drinking by *boiling*. Boiling for 10-15 minutes kills almost all bacteria which cause disease.

(ii) *Town Supplies*.—It is impossible to boil all the water used in a town. Large supplies of water for drinking and for household purposes may be purified by two main methods:—(a) The water is filtered through beds of sand and small stones, as shown in the

diagram, so that suspended impurities are filtered out. (b) The water is treated with some substance which kills the bacteria, e.g. *chlorine* (a greenish-yellow gas with a pungent smell) is used for this purpose in many towns. Only small quantities of chlorine are needed, about one part of chlorine to every two million parts of water.

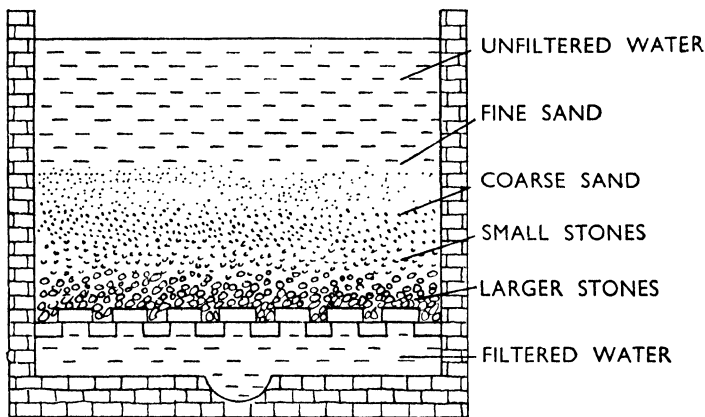


FIG. 60. SAND FILTER

For maximum* safety both methods (a) and (b) are used, one after the other, so as to make quite sure that the water is free from bacteria and contains no organic matter on which bacteria might feed. The water used in modern swimming-pools is usually made safe by the same methods, being continuously circulated through filters and chlorinated.†

CHEMICALLY PURE WATER—DISTILLED WATER

For some purposes, *chemically pure water*, free from all dissolved substances, is required, e.g. for use in the laboratory, for making up medicines, for adding to accumulators† (car batteries†), and sometimes for making ice. Filtering will not remove *dissolved* substances, hence such water is got by distillation. In distillation,

the water is boiled and the steam is caught and condensed. The dissolved substances are not changed into vapour when the water is boiled, but they remain behind in the boiler. The liquid which condenses is called *distilled water* and it is quite pure. (Rain, of course, is natural distilled water, but it is seldom quite pure since it washes the air on its way down to earth.) We shall now imitate the natural processes of evaporation and condensation.

TO OBTAIN PURE WATER FROM SEA-WATER

Fit up the apparatus shown in the diagram, and in the boiling-flask put some sea-water which has been coloured with a little ink.

Describe the taste of this water.

Heat the flask and boil the water. When about half the coloured sea-water has boiled away, turn out the burner and examine the liquid which has collected in the other flask.

Describe its taste.

Evaporate about 5 c.cm. of it on a clean watch-glass over a water-bath.

Is there any solid residue ?.....

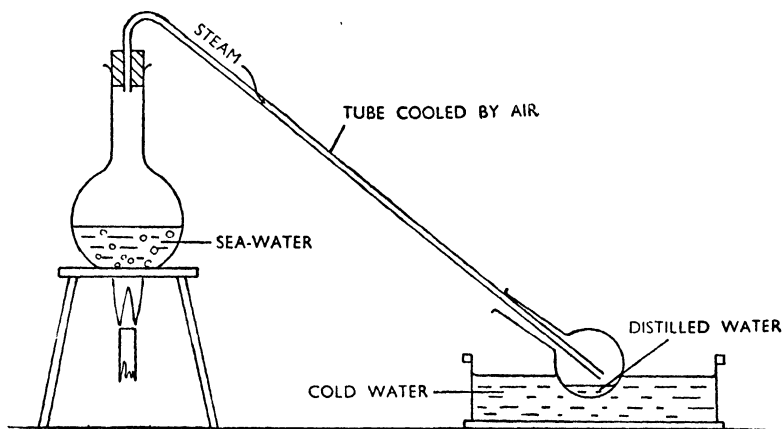


Fig. 61. SIMPLE DISTILLING APPARATUS

Your apparatus was a very simple form of distilling apparatus. Your teacher will show you a better arrangement in which the steam is condensed as it passes through a tube cooled by water, as shown in the diagram.

Distillation is important because it enables us to separate mixtures of liquids of different boiling-points, e.g. raw *petroleum*, as it comes out of an oil-well, is a mixture of many different substances which are separated from each other by distillation. When petroleum is distilled in this way, over 200 commercial

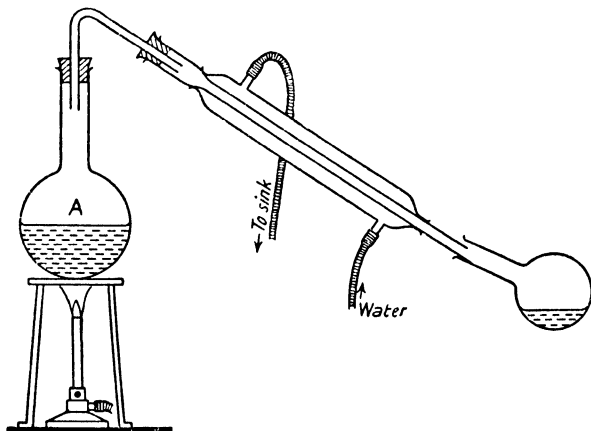


FIG. 62. DISTILLATION

products are obtained, all with different boiling-points, e.g. petrol distils off first, then kerosene, then Diesel-oil,† then lubricating* oil, and then petroleum jelly (or vaseline). In many power-stations, all the water used in the boilers is distilled first. If water containing dissolved mineral matter is used the mineral matter is left behind in the boilers and, in time, spoils them.

THE PHYSICAL PROPERTIES OF PURE WATER

The taste of distilled water is usually described as 'flat'. This is because it contains no dissolved air or mineral matter

which give natural waters their taste. If some distilled water is shaken up with air and then tasted, it tastes more like ordinary tap-water.

Pure water is a liquid which has neither colour, taste nor smell. It leaves behind no residue on evaporation. It boils at 100°C . (or 212°F .), and freezes to ice at 0°C . (or 32°F .). 1 c.cm. of pure water weighs 1 gm. (In fact, in the early days of the *Metric System* the gram weight was the weight of a cubic centimetre of water.) Water is a very good *solvent* and dissolves almost every substance to some extent. (The slight residue left on your watch-glass after the evaporation of some distilled water has been dissolved from the glass of your apparatus.) This is why it is so difficult to get perfectly pure water, quite free from the slightest trace of any dissolved matter.

THE DECOMPOSITION OF WATER BY ELECTRICITY

If the two wires coming from an electric battery are held a short distance apart in water containing a little acid, bubbles of gas form on the wires and rise to the surface. The diagram shows how to collect these gases to examine their properties and find out what the gases are.

The glass trough is half-filled with water to which a little dilute sulphuric acid† has been added. The glass tubes are filled with water and inverted over two small plates of thin metal connected to wires from the battery. (*Platinum* is the metal generally used for these plates since it is not dissolved by acids or attacked by the gases given off.) When these two platinum plates (or electrodes†) are connected to the battery, an electric current passes from one plate to the other through the water. Bubbles of gas form on the electrodes and

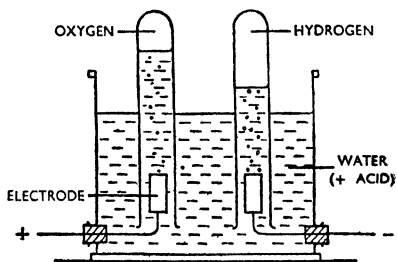


FIG. 63. ELECTROLYSIS OF WATER

collect in the two glass tubes. More gas collects in one tube than in the other: in fact, one electrode gives off *twice* as much gas as the other.

On testing the gases in the tubes with a lighted wooden splinter, the *smaller* quantity of gas makes the splinter burn much brighter. This gas is therefore *oxygen*. The *larger* quantity of gas catches fire with a slight explosion and burns with a faint blue flame. This gas is *hydrogen*.

These two gases, *hydrogen* and *oxygen*, are set free from water just as mercury and oxygen are set free when mercuric oxide is heated, i.e. by breaking up the original substance into its constituents. We have learnt that such a decomposition is called *analysis*. But this particular kind of analysis is brought about by using an electric current, hence a good name for the process would be *electro-analysis*. This long word is shortened to electrolysis,† and we say that we have electrolyzed water. By the electrolysis of water we can show that *water is a compound of hydrogen and oxygen in the proportion of two volumes of hydrogen to one volume of oxygen*.

A little sulphuric acid was added to the water in the last experiment to make it conduct* the electric current, since pure water is a non-conductor of electricity. As sulphuric acid contains both hydrogen and oxygen it may be thought that the hydrogen and oxygen collected in the tubes come from the acid and not from the water. That this is not so, is shown by the fact that if a measured quantity of sulphuric acid is added at the beginning of the experiment, the amount of acid does not get less, however long the electrolysis is carried on. (In the same way, an accumulator or motor-car battery never needs more acid, but only more pure water to take the place of the water lost by 'gassing' when the accumulator is fully charged. The bubbles of gas given off by an accumulator during charging consist of two volumes of hydrogen mixed with one volume of oxygen, and as this is an explosive mixture, no flame should be brought near an open accumulator.)

We have now split up water into hydrogen and oxygen (*analysis*). In a later lesson we shall see if we can produce water by making hydrogen combine with oxygen (*synthesis*), i.e. now that we have 'taken water to pieces' we shall try to 'put it together again'. Before doing this, we shall make hydrogen in larger quantities and examine its properties.

HYDROGEN

The electrolysis of water is a way of making hydrogen which is used to manufacture large quantities of hydrogen commercially. In the laboratory, however, it is more convenient to prepare hydrogen by dissolving a metal in either dilute sulphuric acid or dilute hydrochloric acid (but *not* nitric acid,† which cannot be used for preparing hydrogen).

TO PREPARE A LITTLE HYDROGEN

(i) Add about 5 c.cm. of dilute sulphuric acid to a small piece of zinc in a test-tube. Notice that bubbles of gas are given off. (If the action is slow, add a few drops of copper sulphate solution to act as a catalyst.) Bring a flame near the mouth of the tube and notice that the gas burns with a faint blue flame. (If the gas is mixed with air there will be a slight explosion.) The gas is *hydrogen*.

(ii) Repeat the experiment, using *zinc* and dilute *hydrochloric acid*.

What happens ?.....

(iii) Repeat the experiment, using *iron* filings and dilute *sulphuric acid*.

What happens ?.....

(iv) Repeat the experiment, using *iron* filings and dilute *hydrochloric acid*.

What happens ?.....

(v) Repeat the experiment, using *magnesium* and dilute *sulphuric acid*.

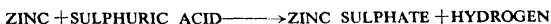
What happens ?.....

(vi) Repeat the experiment, using *magnesium* and dilute *hydrochloric acid*.

What happens ?.....

TO PREPARE SEVERAL JARS OF HYDROGEN

In the laboratory, hydrogen is usually prepared by treating *zinc* with *dilute sulphuric acid*.



Use the apparatus shown in the diagram. The flask is fitted with a two-hole rubber cork, one hole carrying the delivery-tube

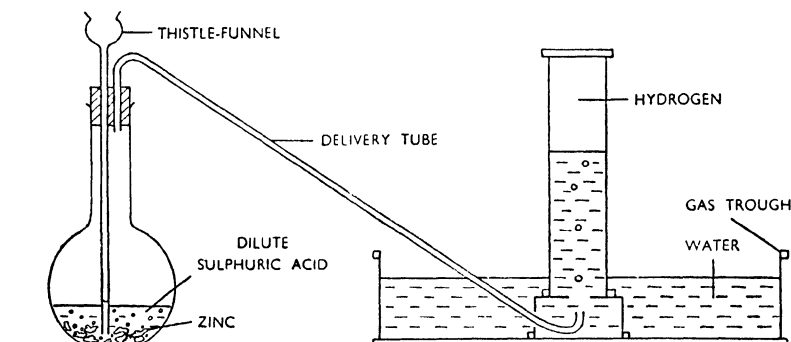


FIG. 64. PREPARATION OF HYDROGEN

and the other carrying a thistle-funnel† through which the acid is poured on the zinc. *Slide* some small pieces of zinc (about 10 gm.) into the flask and cover it with a test-tube full of water. Add a few c.cm. of copper sulphate solution.

What happens ?.....

This will act as a catalyst and make the hydrogen come off more easily.

See that the thistle-funnel has its bottom end dipping below the surface of the water in the flask. Then ask your teacher to approve your apparatus. (*N.B.—There must be no flame on the*

bench while you are preparing hydrogen, otherwise there may be a dangerous explosion.)

When the teacher has passed your apparatus, pour about 40 c.cm. of dilute sulphuric acid down the thistle-funnel. (N.B.—*Not* the bench reagent, which is too dilute, but that supplied by your teacher and prepared beforehand by adding one volume of concentrated* sulphuric acid to three volumes of water and then cooling.)

After waiting a short time for the air to be pushed out of the apparatus, invert a test-tube full of water over the end of the delivery-tube and collect a test-tube full of the gas. When it is full, close the mouth of the test-tube with your thumb and bring it, mouth downwards, to a flame *on another bench*. If it explodes, your apparatus still contains some air, so collect another sample and test again in the same way. When the gas burns quietly in the test-tube, collect three jars of hydrogen, close them with gas-jar covers and keep them mouth downwards on the bench. When you have collected these three jars of hydrogen, put your apparatus out of the way before lighting the burner on your bench. Do the following experiments:—

1st Jar.—(a) Describe the colour of the gas.....

Hydrogen prepared by this method contains a strong-smelling impurity, hence you will be unable to describe the smell of *pure* hydrogen.

(b) Hold the mouth of the inverted jar near a flame.

What happens ?.....

Why ?

2nd Jar.—Hold the jar, mouth downwards; remove the cover and quickly push a lighted wooden splinter up into the jar.

What happens *to the hydrogen* ?.....

What happens *to the lighted splinter* ?.....

3rd Jar.—Invert a jar of air over the third jar of hydrogen so that the two jars are mouth-to-mouth. Wrap the inverted jar with a cloth to prevent the glass from flying if it breaks. Remove the cover between the jars, and after waiting for a second or two,

remove the top jar (which originally contained air) and hold it to a flame.

What happens ?.....

What do you learn from this ?.....

Now hold the bottom jar to a flame.

What happens ?.....

Why ?

THE PROPERTIES OF HYDROGEN

Pure hydrogen is a gas without colour, taste, or smell. (The hydrogen obtained when commercial zinc, or iron, is dissolved in acids has an unpleasant smell, but the smell is due to the impurity and not to the hydrogen itself.) Hydrogen is the lightest substance known. (Air is over fourteen times heavier than hydrogen.) Hydrogen is practically insoluble. When a light is put to hydrogen, it burns quietly, with a very faint blue flame, but if air is mixed with it, then the mixture explodes when lighted.

Hydrogen will not allow things to burn in it, i.e. it does not support combustion.

Your teacher will demonstrate the extreme 'lightness' of hydrogen by filling a small, thin rubber balloon with *dry* hydrogen (two drops of water weigh as much as one litre of hydrogen !). The balloon rises in the air, just as a cork rises to the surface when put under water. Soap bubbles filled with hydrogen will also

rise in the air. Compare this with balloons and soap bubbles which have been filled with *air*.

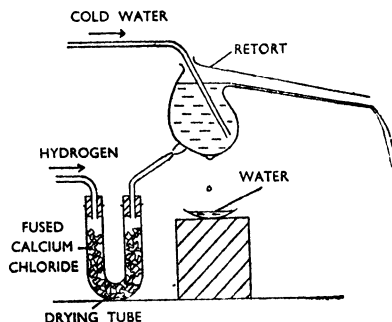


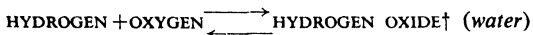
FIG. 65. BURNING HYDROGEN IN AIR

BURNING HYDROGEN IN AIR

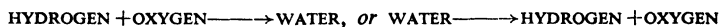
In some of our earliest experiments we saw the result of burning candles in jars of air over water. In every case we found that part of the air was used up (the oxygen) and

a *dew* appeared on the inside of the jar. We shall now see what happens when *hydrogen* burns in air.

Hydrogen prepared in the usual way from zinc and dilute sulphuric acid is dried by passing it through a 'U'-tube containing fused calcium chloride as shown in the diagram. After making sure that the gas is not mixed with air, the dry hydrogen is lighted as it comes out of the metal jet.* The flame of the burning hydrogen is then allowed to touch the dry surface of a flask (or a retort†) which is kept cool by running water. (This experiment gives you a good chance to see the colour of the hydrogen flame.) Drops of liquid condense on the outside of the cold flask and can be collected on a watch-glass. The liquid has no colour, taste, or smell. It turns white (anhydrous) copper sulphate blue, therefore it contains *water*. Hence, *water is formed when hydrogen burns in air*. The chemical name for water is therefore *hydrogen oxide*.



The sign $\begin{array}{c} \longrightarrow \\ \longleftarrow \end{array}$ means that the reaction can go either way, *either*



In words, by making hydrogen and oxygen combine together we get water. This is synthesis. On the other hand, we can also split up water into hydrogen and oxygen, e.g. by passing through it an electric current. This is analysis.

The last experiment explains the formation of dew when a candle is burnt in a jar of air. Candle-wax is a compound containing carbon and hydrogen. The carbon burns to form carbon dioxide, while the hydrogen burns to form hydrogen oxide, i.e. water, which condenses on the glass of the jar. Hydrogen received its name from Lavoisier in 1783, and the word means '*the Water Producer*'.

USES OF HYDROGEN

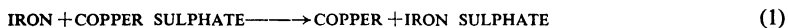
Since it is so 'light', hydrogen is used for filling balloons and airships, although it has the very serious disadvantage that it

catches fire very easily, thus causing terrible accidents. We have learnt that *helium*, the second lightest gas, is much safer because it will not burn. The chief uses of hydrogen are in chemical industries, e.g. in 'hardening' liquid *oils* obtained from plants and animals (such as palm oil† and whale oil†) so as to change them into solid *fats* which can be used for food, for cooking purposes, and for making soap. We shall learn later how hydrogen is used in the manufacture of ammonia† and in making fuel-oil from coal. We have already seen that it is used in producing the very hot *oxy-hydrogen* flame (p. 54).

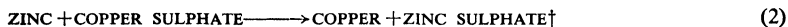
THE DISPLACEMENT OF HYDROGEN FROM ACIDS BY METALS

We have seen that several common metals dissolve in acids, setting free hydrogen. They are said to *displace hydrogen from acids*, the metal taking the place of the hydrogen.

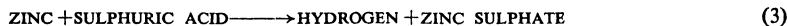
This reminds us of what happens when an iron nail is put in copper sulphate solution (p. 28).



In the same way, when we added copper sulphate solution to the zinc when we prepared hydrogen (p. 109), the zinc became coated with copper, *displaced from the copper sulphate*.



Zinc dissolves in dilute sulphuric acid, displacing hydrogen in just the same way:



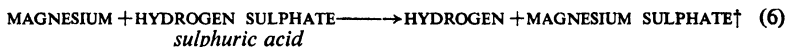
It is clear that, in this reaction, hydrogen has taken the place of copper in equation (2): in fact, we can write hydrogen sulphate† instead of *sulphuric acid*, thus showing its chemical composition more clearly.



Similarly



and



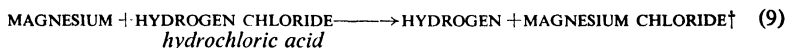
In the same way, another chemical name for *hydrochloric acid* is hydrogen chloride,† hence we can write:—



and



and



The important thing to notice about all the reactions (3) to (9) is that in every case *the metal displaces the hydrogen of the acid*.

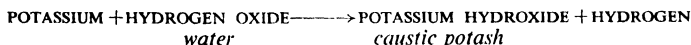
THE DISPLACEMENT OF HYDROGEN FROM WATER BY METALS

Just as many metals displace hydrogen from acids, some metals will displace hydrogen from *water*, under suitable conditions. Thus, the very active metals *potassium* and *sodium* displace hydrogen from cold water, at the same time dissolving in the water. (You will remember that potassium and sodium are bright, silvery metals which are so soft that they can be cut with a knife. They rust so rapidly in air that they have to be kept under *kerosene*, an oil which contains *no oxygen*. As these elements are so very active it will be safer if your teacher demonstrates the next two experiments to you.)

TO OBSERVE THE ACTION OF POTASSIUM ON WATER

When a small piece of potassium is dropped into an evaporating dish containing water coloured red with litmus, the reaction is so vigorous that the metal melts and runs about on the surface of the water. (Potassium is 'lighter' than water.) Hydrogen is given off and it catches fire of itself owing to the great heat of the reaction, burning with a pale purple flame because some

potassium vapour is mixed with the hydrogen. (Any compound containing potassium colours a flame pale purple.) The litmus turns blue because potassium hydroxide† (caustic potash), an alkali, is formed. Hence, *potassium easily displaces hydrogen from cold water, or*



TO OBSERVE THE ACTION OF SODIUM ON WATER

A dry glass tube (about 6 in. by $\frac{1}{2}$ in.) is clamped upright with its lower end dipping about 1 in. under some water in a glass dish, as shown in the diagram.

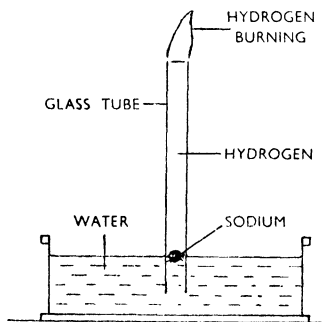
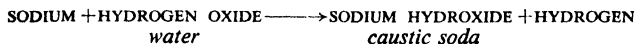


FIG. 66. ACTION OF SODIUM ON WATER

The water is coloured red with litmus and a small piece of sodium is dropped into the tube. There is a vigorous reaction (although not quite so vigorous as when potassium is used, since the hydrogen does not catch fire of itself).

The sodium melts and jumps about on the surface of the water. (Sodium is 'lighter' than water.) When a light is put to the mouth of the tube, the hydrogen catches fire and burns with a bright yellow

flame, because some sodium vapour is mixed with the hydrogen. (Any compound containing sodium colours the flame bright yellow.) The litmus turns blue because *sodium hydroxide*† (caustic soda) is formed when the sodium reacts with the water, and the solution feels slippery, or 'soapy', when rubbed between finger and thumb. Hence, *sodium easily displaces hydrogen from cold water, or*



TO OBSERVE THE ACTION OF CALCIUM ON WATER

The metal calcium does not combine with oxygen so easily as sodium and potassium, hence its action on water is not so vigorous. As calcium sinks in water we can collect the hydrogen in an inverted test-tube. Invert a test-tube filled with water over a piece of calcium in a dish of water. When the test-tube is full of the gas, test it.

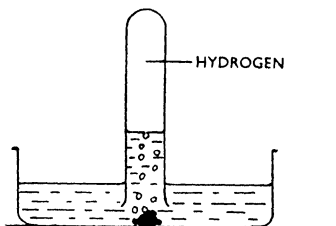
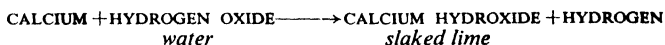


FIG. 67. ACTION OF CALCIUM ON WATER

Then filter a little of the water used in this experiment and breathe through the filtrate.

What happens ?

Hence the liquid is *lime-water*, made by dissolving calcium in water. (We usually make lime-water by dissolving lime or slaked lime in water.) Hence, *calcium displaces hydrogen from water fairly easily*.



The only common elements which can displace hydrogen from cold water are *potassium*, *sodium*, and *calcium*, but some other metals, e.g. magnesium and iron, although they will not displace hydrogen from cold water, will do so from *steam*, if the metals are heated.

TO OBSERVE THE ACTION OF HEATED MAGNESIUM ON STEAM

A flask is half-filled with water and fitted with a cork carrying a *safety-tube* and a delivery-tube for the steam, as shown in the diagram. The water is boiled, and when steam comes out of

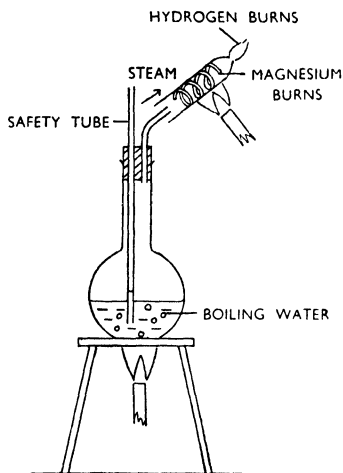
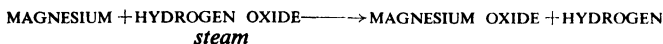


FIG. 68. ACTION OF MAGNESIUM ON STEAM

the delivery-tube, the tube containing the magnesium is heated and placed over the end of the delivery-tube so that steam passes over the hot magnesium. After further heating, the magnesium catches fire and burns brightly in the steam, just as it burnt in air in our early experiments. The magnesium combines with the oxygen of the steam (hydrogen oxide) forming magnesium oxide. At the same time, hydrogen is displaced from the steam and burns at the end of the tube. Hence, *heated magnesium displaces hydrogen from steam, or*



TO OBSERVE THE ACTION OF HOT IRON ON STEAM

The apparatus shown in the diagram is used for passing steam over iron powder in a 'hard' glass tube which is strongly heated. The oxygen of the steam combines with the iron, forming iron oxide, and hydrogen is displaced, collecting in the gas-jar. (This is not the same oxide which is present in iron rust, but it has the same composition as the iron oxide formed when iron is burnt in oxygen.)

Hence, *hot iron displaces hydrogen from steam, or*



The last five experiments show that we have a series of metals which displace hydrogen less and less easily from potassium down to iron, in the following order:—(1) *Potassium*, (2) *Sodium*,

(3) *Calcium*, (4) *Magnesium*, (5) *Iron*. In other words, *potassium is more active chemically than sodium, while sodium is more active than calcium, and so on, down to iron, which is the least active of these five elements. Copper, silver, and gold are still less active: they never displace hydrogen from water or acids.*

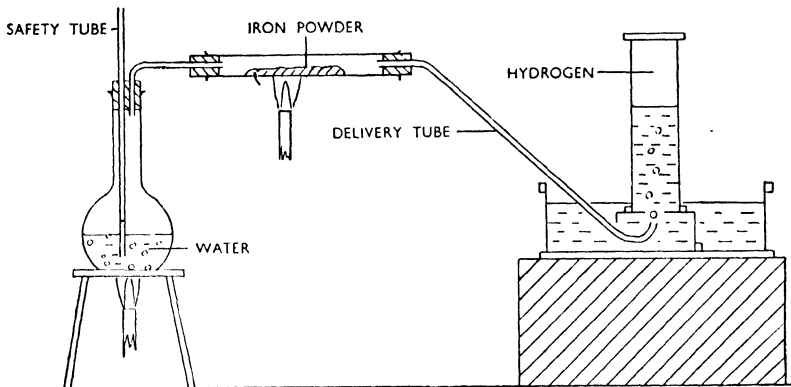


FIG. 69. ACTION OF IRON ON STEAM

QUESTIONS

1. The splitting-up of a substance into its constituents by means of an electric current is called.....
2. What substance is used as a test for the presence of small quantities of water ?
3. Pure water does not conduct electricity. How can you make it conduct an electric current ?
4. Chemically pure water is prepared by.....
5. Write down the following metals in the order of their chemical activity: the most active first:—magnesium, iron, sodium, calcium.
6. Water which is to be used for drinking should be free from

7. A small quantity of water can be made safe for drinking by
.....
8. What is the purest form of water in Nature ?
9. Write ONE word which means ' the process of changing a liquid into its vapour and then recovering the liquid by condensing the vapour '.
10. What is the disadvantage of hydrogen for filling airships ?
11. Name one metal which is ' lighter ' than water.
12. How would you dry some damp hydrogen ?
13. What is the meaning of the word ' anhydrous ' ?
14. Name the ' lightest ' element.
15. Name all the substances produced when zinc reacts with dilute sulphuric acid.

Note.—Before reading this chapter study Appendix III and Appendix IV.

CHAPTER VI

MEASUREMENT

It is sometimes said that ‘*Science is measurement*’, and there is a lot of truth in this because most of our present knowledge about the things of everyday life is the result of careful measurement. Science made little progress for about 2,000 years because early scientific ideas were based only on what men *thought* of things, i.e. mere *opinions*, and it was not until careful measurement was introduced that scientific ideas could be based on *facts*. In our earliest lessons on air, we had to measure *weight* and *volume* before we could explain what air *is*. In later lessons you will find that, until you can *measure* them, you will know very little about pressure, heat, force, mechanical work, electricity, chemical change, food values, and so on. All scientific measurement is based on measuring the three different kinds of *quantities*—*length*, *weight*, and *time*—and all our other measurements can be stated in *units* of length, weight, and time.

HISTORICAL UNITS OF LENGTH

The measurement of *length* (and if you can measure lengths you can also measure *areas* and *volumes*) has always been a matter of great everyday importance, and from the earliest times, every nation of any civilization has used some *units* or other. The oldest units of length were taken from parts of the human body. For example, in the Old Testament we read about cubits.† This cubit, used by the Egyptians, the Jews, and the Greeks, was the distance from the point of the elbow* to the tip of the middle finger, i.e. about 18 inches. A *span*† was the distance from the tip of the thumb to the tip of the little finger with the fingers stretched out to their fullest extent, i.e. about 9 inches (or half

a cubit). A palm† was the width of the palm* of the hand, i.e. about 3 inches (one-third of a span, or one-sixth of a cubit). A digit† was the width of a finger, about $\frac{3}{4}$ in. (one-quarter of a palm, or one-twentyfourth of a cubit). Nearly every nation has used a unit which corresponds* to our *foot*, and this came from the length of a man's foot. The English *yard* is said to have been the length of the arm of the English King Henry the First, the English *foot* was the length of his foot and the *inch* was the width of his thumb. (King Henry was clearly an exceptionally big man !)

Some English units of length came from agriculture* in Anglo-Saxon times. The pole,† or rod† ($5\frac{1}{2}$ yards, or 16 ft. 6 in.) was the length of the long wooden pole carried by the farmer when ploughing with eight oxen. A pole of this length, with a sharp point at one end, was used to prick* the front oxen when they went too slowly. When the farmer wanted to measure the length of a piece of ground, he would naturally use this long pole, and since all farmers used poles of nearly the same length, the *pole* became a unit of length. A furlong† is a shortened form of 'a furrow* long', this being the length of furrow that oxen could plough without stopping for a rest; and this length, being forty poles, could be measured off by the farmer with his wooden pole.

In olden times, therefore, each nation had its own system of measurement just as it had its own language, both being equally difficult for foreigners to understand. As trade grew, it became necessary to have uniform standards to do away with this confusion in buying and selling. Uniform standards also stop cheating. For example, if cloth was sold by the cubit, measured off by a man's arm, dishonest shopkeepers would employ only small men with short arms for selling cloth.

Two systems of measurement are used in English-speaking countries, (a) *the Imperial System*,† and (b) *the Metric System*.†

BRITISH UNITS OF LENGTH

The British Unit of Length was defined* by law in 1878 as the *Imperial Standard Yard*. *The Imperial Standard Yard is the*

distance between two marks on a certain bar of metal kept in London. All our yard measures are copies of this length, and all other British units of length are got from the Standard Yard: thus, a foot is one-third of a yard; an inch is one-twelfth of a foot or one-thirty-sixth of a yard, and so on.

British measures have two disadvantages:—(a) They are difficult to calculate with; thus, if you want to change miles to yards, or yards to poles, you have to multiply or divide by awkward numbers. (b) There is no simple relation between the units of length, volume, and weight, i.e. between the *yard*, the *gallon*, and the *pound* (e.g. there are $272\frac{1}{4}$ sq. ft. in a sq. pole and $34\frac{2}{3}$ cu. in. in a pint). A better system of weights and measures is that based on the metre,† namely, the *Metric System*.

THE METRIC SYSTEM

At the time of the French Revolution (which began in 1789) the inconvenience and confusion caused by the older systems of measurement caused the new Republican Government to appoint a committee of scientific men (Lavoisier being one of them) to work out a better and simpler system. This committee produced the *Metric System*, which is now used all over the world for scientific purposes, and in some countries for everyday purposes as well.

The metric unit of length is the Standard Metre.† *The Standard Metre is the distance between two marks on a certain bar of metal kept in France.* (This distance is 39·37 inches.) For most scientific purposes we measure lengths in centimetres† (hundredths of a metre) or in millimetres† (thousandths of a metre).

The metric unit of *volume* is the litre.† This is the volume of *one cubic* decimetre*, i.e. the volume of a cube whose sides are one-tenth of a metre long. Hence 1 *litre* = 1,000 *cubic centimetres*.

The metric unit of *weight* is the kilogram,† and this is the weight of a certain lump of platinum kept in France, which has the same weight as *one litre of pure water at 4° C.* For practical purposes, the *gram*† is the weight of one cubic centimetre of water.

BRITISH SYSTEM

METRIC SYSTEM

12 inches (in.)=1 foot (ft.)	10 millimetres (mm.) =1 centimetre
3 feet =1 yard (yd.)	10 centimetres (cm.) =1 decimetre
5½ yards =1 pole	10 decimetres (dm.)† =1 metre
40 poles =1 furlong	10 metres (m.) =1 dekametre
8 furlongs =1 mile	10 dekametres (Dm.)†=1 hectometre
3 miles =1 league	10 hectometres (Hm.)†=1 kilometre†

*Useful Equivalents.**—1 yard=0·9 metre. 1 mile=1·6 kilometres (km.). 1 kilometre=5 furlongs.

Not all of these units are in common use and we shall only use the following in this science course:—metre (m.), kilometre (km.), centimetre (cm.), millimetre (mm.), litre (l.), cubic centimetre (c.cm.), gram (gm.), kilogram (Kg.).

The Metric System has the following advantages:—(a) *It is a decimal* system.* This makes the metric tables very simple indeed since they have only one number—10—to multiply or divide by. Because of the awkward numbers involved* we have all spent many hours in learning the tables for the British system of weights and measures. In the metric tables (b) the figures remain the same and it is only necessary to move the decimal point in changing from one unit to another; (c) *there is a simple relation between the units of length, volume, and weight*, e.g. a litre is a cubic decimetre, and a kilogram is the weight of a litre of water.

MEASUREMENT OF LENGTH

TO MEASURE THE LENGTH OF A STRAIGHT LINE ACCURATELY

Examine your ruler, and notice that one edge is divided into inches and tenths of an inch, while the other edge is divided into centimetres and tenths of a centimetre (millimetres). (N.B.—In the following exercises on measurement, use *decimals* and not fractions, giving your results to *three significant* figures* only.) Draw three straight lines on paper, AB=3·00 in., CD=4·00 in.,

and $EF=5.00$ in. long. Measure these lines in centimetres and tenths of a centimetre, taking the following precautions* :—

(a) Unless the ruler has a very thin edge, place it on its side, i.e. with the marks on the ruler as near as possible to the point to which you are measuring. (b) If the marks begin at the very end of the ruler, do not use the end marks, but measure ‘by difference’. (c) Keep your eye vertically* over the point you are measuring to. From your results, calculate the number of centimetres in one inch.

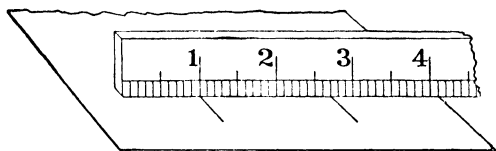


FIG. 70. HOW TO USE A RULER

- (i) $AB=3.00$ in. = cm., therefore, 1 inch = centimetres.
- (ii) $CD=4.00$ in. = cm., therefore, 1 inch = centimetres.
- (iii) $EF=5.00$ in. = cm., therefore, 1 inch = centimetres.

Since the *average* of several results is nearer the truth than one single measurement, take the average of these three results.

3).....

Therefore, 1 inch = centimetres.

Draw a graph* which will enable you to turn inches into centimetres without calculation.

TO MEASURE THE LENGTH OF CURVED LINES

Draw a circle of 2.00 in. radius† on a sheet of paper. Tie a small knot near the end of a piece of cotton thread and, marking the circle where you start, lay the knot on the mark and measure the length of the circumference† of the circle, laying the thread along the line a little at a time and holding it down with the fore-finger of each hand. When you come to the starting-point,

hold the thread at this point and lay it straight along your ruler, reading off the length in centimetres.

Do this three times and find the average.

Circumference of circle=(i) cm. (ii) cm.
(iii) cm.

Therefore, average result=..... \div 3=..... cm.

A better way of measuring the length of a curved line is to use a *map-measurer*. This has a little rough-edged wheel mounted on an axle which is a fine screw. The wheel is first screwed along to the end of the axle* near the pointer, and the mark on the wheel is set opposite the pointer. To measure the length of a curved line, the map-measurer is held upright with the pointer over the end of the line to be measured, and it is then wheeled along the line to its other end. The map-measurer is then wheeled backwards along a ruler until the mark on the wheel reaches the pointer again, and the distance travelled along the ruler is the length of the line. Measure, in centimetres, the circumference of your 2 in. circle by this method. Do this three times and find the average.

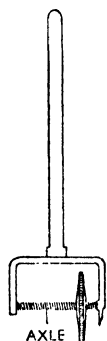


FIG. 71.
MAP
MEASURER

Circumference of circle=(i) cm.
(ii) cm. (iii) cm.

Therefore, average result=..... \div 3=..... cm.

From a map of your district, find how far you actually travel to school. Measure the distance on the map, (i) using a map-measurer, and (ii) using a piece of thread.

(i) Distance on map (using map-measurer)=..... in.
But inch on the map=..... miles on the ground.
Therefore, distance travelled to school=..... miles yards.

(ii) Distance on map (using a piece of thread)=..... in.
But inch on the map=..... miles on the ground.
Therefore, distance travelled to school=..... miles yards.

Which do you think is the more accurate result, (i) or (ii) ?

Why ?

How far is it from your house to the school *in a straight line* ?

.....
Measure the circumference of the given cylinder by wrapping a piece of thread round it ten times. Unroll the thread and measure the length of ten complete turns. Do this three times and find the average.

Ten times the circumference=(i) cm. (ii) cm. (iii) cm.

Therefore, average result for ten times circumference= $\div 3$ = cm.

Therefore, circumference of cylinder= $\div 10$ = cm.

Measure the circumference of the given wooden disc by wrapping a strip of paper round it so as to overlap, and prick a hole with a pin through the overlapping part. Unwrap the paper, lay it flat, and measure the distance between the holes. Do this three times and find the average.

Circumference=(i) cm. (ii) cm. (iii) cm.

Therefore, average circumference of disc= $\div 3$ = cm.

Take a large coin or washer* and put a tiny spot of ink on its edge. Roll it along a piece of paper so that it leaves at least two marks on the paper. Measure the distance between two marks. Do this three times and find the average.

Circumference=(i) cm. (ii) cm. (iii) cm.

Therefore, average circumference= $\div 3$ = cm.

TO MEASURE THE DIAMETER OF A CYLINDER

Arrange two set-squares, a ruler, and the given cylinder as shown in the diagram. Measure the diameter* three times,

turning the cylinder and using a different part of the ruler each time. Find the average of your three measurements.

Diameter of cylinder=(i) cm. (ii) cm.
(iii) cm.

Therefore, average diameter = \div 3 = cm.

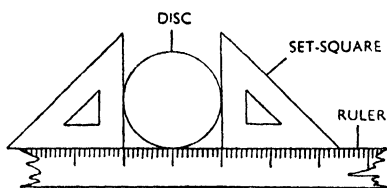


FIG. 72. MEASURING THE DIAMETER OF A CYLINDER

ball-bearing*) as shown in the diagram. Measure the diameter of the sphere three times, using a different part of the ruler each time, and turning the sphere between each measurement.

Diameter of sphere=(i) cm. (ii) cm.
(iii) cm.

Therefore, average diameter of sphere = \div 3 = cm.

TO MEASURE THE DIAMETER OF A SPHERE

Arrange two square wooden blocks, a ruler, and the given sphere* (e.g. a

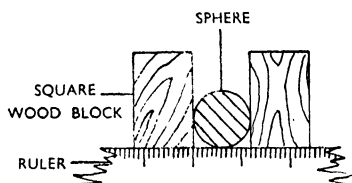


FIG. 73. MEASURING THE DIAMETER OF A SPHERE

TO USE THE OUTSIDE CALIPERS

Use the outside calipers† to measure the diameter of the given sphere, opening the calipers so that the widest part of the sphere will just slip between, without being scratched. Then measure the distance between the points of the calipers with a ruler. Make three measurements of the diameter, turning the sphere between each measurement.

Diameter of sphere=(i) cm. (ii) cm.
(iii) cm.

Therefore, average diameter of sphere = \div 3 = cm.

TO USE THE INSIDE CALIPERS

Use the *inside calipers* to measure the inside diameter of the given metal tube. Make three measurements of the tube in different positions and find the average.

Inside diameter = (i)
cm. (ii) cm. (iii)
..... cm.

Therefore, average inside
diameter = $\div 3$ =
cm.

THE VERNIER

The vernier† is a very useful device* for measuring fractions of scale divisions accurately, e.g. to 0.01 in. or to 0.01 cm. It consists of a short *vernier scale* sliding alongside the *main scale*, and marked so that 10 *vernier divisions* = 9 *scale divisions*, e.g. on a centimetre vernier, 10 vernier divisions = 9 mm., or 1 vernier division = 0.9 mm. In the first diagram, the distance

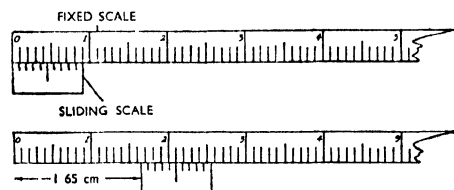


FIG. 75. THE VERNIER

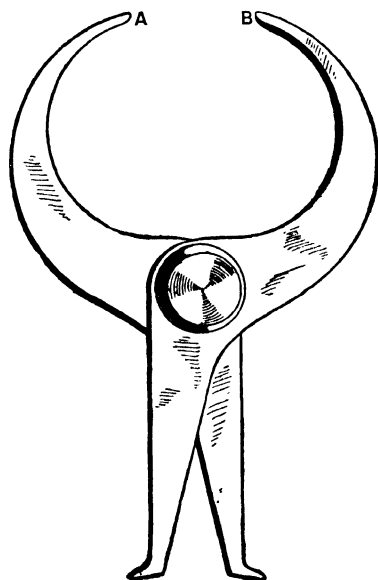


FIG. 74. CALIPERS

between the first mark on the fixed scale and the first mark on the vernier scale is 0.1 mm. Similarly, the distance between the second mark on the fixed scale and the second mark on the vernier scale is 0.2 mm., and so on, until the distance between the ninth scale division and the ninth vernier division is 0.9 mm.

The second diagram shows how a vernier works. The reading (opposite the arrow on the vernier) is 1.6 cm. *plus* a fraction of a millimetre*. Looking along the vernier, we see that the fifth division of the vernier is exactly opposite a division on the fixed scale. Looking to the left of this, the fourth vernier mark is 0.1 mm. to the right of the next fixed scale mark. Similarly, the third vernier mark is 0.2 mm. to the right of the next mark on the fixed scale, and so on, until we reach the zero mark on the vernier, which is 0.5 mm. to the right of the 1.6 cm. mark on the fixed scale, i.e. *the reading opposite the arrow is 1.65 cm.*

When using a decimal vernier, therefore, *look along the vernier until you find a vernier mark which is exactly opposite a mark on the fixed scale: the number of this vernier mark gives the required decimal.*

TO USE THE VERNIER SLIDING CALIPERS

Before using the instrument, the first thing to do is to close its *jaws* and see whether the zero mark on the sliding scale is exactly opposite the zero mark on the fixed scale. If these two marks are not exactly opposite each other, then there is a *zero error* which must be noted. If the zero mark on the sliding scale is to the *right* of the zero mark on the fixed scale, then the zero error must be subtracted* from your measurements.

If the zero mark on the sliding scale is to the *left* of the zero

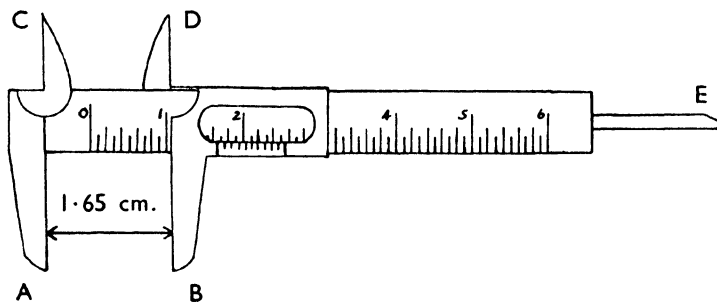


FIG. 76. VERNIER SLIDING CALIPERS

mark on the fixed scale, then the zero error must be *added* to your readings. *Measuring instruments must always be examined for zero error.*

Use the vernier sliding calipers to measure the thickness of fifty pages of this text-book. Hence find the average thickness of one sheet.

Zero error = cm. (State whether + or —.) Scale reading = cm.

Therefore, corrected reading = cm.

But this is the thickness of fifty sheets, hence thickness of one sheet = $\div 50$ = cm.

Measure the outside diameter of the given steel washer, using the *jaws* AB of the vernier sliding calipers.

Zero error = cm. Corrected readings = (i) cm. (ii) cm. (iii) cm.

Therefore, average outside diameter = $\div 3$ = cm.

Measure the inside diameter of the hole in the given washer, using the *ears* CD of the vernier sliding calipers.

Zero error = cm. Corrected readings = (i) cm. (ii) cm. (iii) cm.

Therefore, average diameter of hole = $\div 3$ = cm.

Measure the depth of the hole in the given piece of metal, using the *tail* E of the vernier sliding calipers.

Zero error = cm. Corrected readings = (i) cm. (ii) cm. (iii) cm.

Therefore, average depth of hole = $\div 3$ = cm.

THE MICROMETER† SCREW-GAUGE†

The *screw-gauge* is an instrument for measuring small lengths with great accuracy, e.g. to 0.001 in. or 0.001 cm. When the *screw-head* is given one complete turn, the tip of the screw moves forward by the distance between two threads* of the screw. This distance is called the pitch† of the screw, and it is usually

1 mm. in a metric screw-gauge. There are two scales on a screw-gauge, a *fixed scale* on the body of the instrument and a *revolving** *scale* on the screw-head. On a metric screw-gauge, the fixed scale is divided into millimetres, and the revolving scale is divided into 100 equal parts, so that each of these divisions represents one-hundredth of a complete turn, i.e. 0.001 mm. at the tip of the screw.

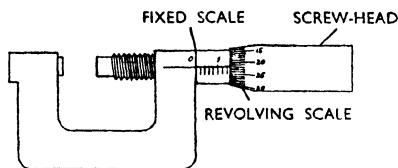


FIG. 77.
MICROMETER SCREW-GAUGE

Examine a screw-gauge, and show your teacher the instrument set to read 1.23 mm. (N.B.—*The screw-head must be turned lightly with the finger and thumb—no force should be used.*)

TO MEASURE THE DIAMETER OF A SMALL SPHERE

First find the zero error of your instrument by reading it when the jaws are closed and remember to add or subtract any zero error from your readings. Then use the screw-gauge to measure the diameter of a small steel ball, in millimetres. Take the average of at least three readings, turning the ball between each measurement.

Zero error = mm. Corrected readings = (i) mm. (ii) mm. (iii) mm.

Therefore, average diameter = $\div 3$ = mm.

TO MEASURE THE DIAMETER OF A WIRE

Use the micrometer screw-gauge to measure the diameter of the given piece of wire, in millimetres. If an inch screw-gauge is available, measure the diameter of the same wire in inches.

Zero error = mm.	Zero error = in.
Corrected readings = (i) mm.	Corrected readings = (i) in.
..... mm. (ii) mm. (iii) mm.	..... in. (ii) in. (iii) in.

Therefore, average diameter = mm.

Therefore, average diameter = in.

MEASUREMENT OF AREA

In mathematics lessons you will have learnt how to find the area of *regular figures* like rectangles,† parallelograms,† triangles and circles, where it is easy to work out simple rules for finding their area. In everyday life, however, it is often necessary to find the area of an *irregular figure*, e.g. the area of an island from a map. This can be done by using squared paper.

TO FIND THE AREA OF AN IRREGULAR FIGURE

Take a sheet of tracing-paper ruled in 1 in. and 0·1 in. squares, and make a careful tracing of the given irregular figure. Find its area by counting the number of squares it contains. Where the edge of the figure cuts a small 0·1 in. square, if more than half the square is inside the figure, count it as one square; if less than half the square is inside, do not count it at all. In this way you will get a fair average for the area of these parts of squares.

Number of small 0·1 in. squares = But 100 small

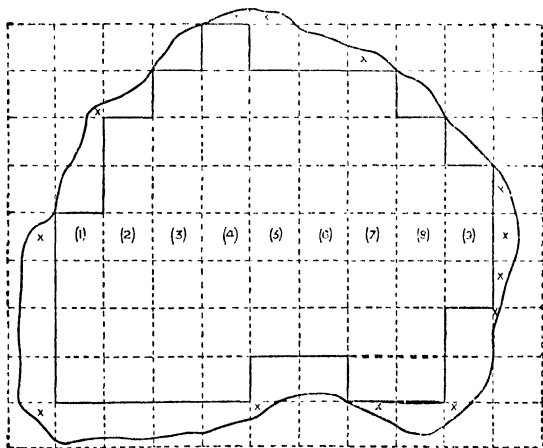


FIG. 78. FINDING THE AREA OF AN IRREGULAR FIGURE

squares make 1 sq. in., therefore area of figure = square inches.

In the same way, find the area of the country you live in, from a map, in square miles.

Area of on map = sq. in.

But 1 in. on the map = miles on the ground, therefore 1 sq. in. on the map = square miles on the ground.

Therefore, area of = by = square miles.

MEASUREMENT OF VOLUME

The volume of anything is the amount of space it occupies, and in mathematics lessons you will have learnt how to find the volume of *regular solids*, e.g. prisms,† pyramids,† and spheres. In everyday life, however, such regular, geometrical solids are rarely met with, and in this science course we shall be more concerned with finding the volume of *irregular solids*, *liquids*, and *gases*. In such cases, the rules for finding the volume of regular solids are of little help.

TO MEASURE THE VOLUME OF LIQUIDS

A liquid has a definite volume but it has no definite shape, hence its volume can be found by pouring it into a graduated* measuring-cylinder. The

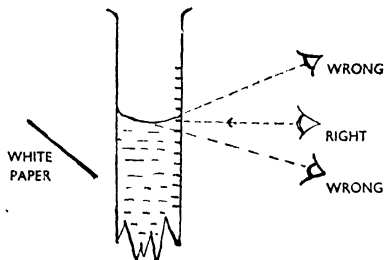


FIG. 79. HOW TO READ THE LEVEL OF A LIQUID

surface of a liquid in a narrow vessel, however, is not flat, but curved, and **when measuring the volume of a liquid in any graduated vessel, you must always read from the surface at the centre of the vessel, with your eye at the same horizontal level.** A piece of white paper held behind the vessel,

and just below the surface, as shown in the diagram, will help you to read off the volume accurately. For measuring the volume of liquids in the laboratory we use *measuring cylinders*, *measuring flasks*, *pipettes*,† and *burettes*.†

THE GRADUATED CYLINDER

The *graduated cylinder* (or *measuring-jar*) is used for rough measurements of the volume of liquids. It is used for *holding* or for *delivering* a measured volume of liquid. Various sizes are used in the laboratory, the commonest being 5 c.cm., 10 c.cm., 25 c.cm., 50 c.cm., 100 c.cm., 250 c.cm., 500 c.cm., and 1 litre.

Examine a graduated cylinder, making sure that you understand how it is graduated. The smallest division on a 100 c.cm. cylinder is usually 1 c.cm., and it is possible to estimate* to one-fifth of this, i.e. 0.2 c.cm. On some cylinders, one set of marks begins at the bottom and these show the volume of liquid *contained* in the cylinder.

Some cylinders have another set of marks beginning at the top and reading downwards, and these marks show the volume of liquid *delivered* from the cylinder after first filling to the top mark. The position of the white paper behind the curved surface and the proper position of the eye are shown in the diagram.

Show your teacher a 100 c.cm. graduated cylinder with 75.0 c.cm. of water in it.

TO FIND THE VOLUME OF AN IRREGULAR SOLID

Put 30.0 c.cm. of water in a 50 c.cm. cylinder, adding the last few c.cm. drop by drop from the tap. Slope the cylinder and slide in the given irregular solid (e.g. a cross-head clamp or a piece of chain) so as not to break the glass or lose any water by splashing.

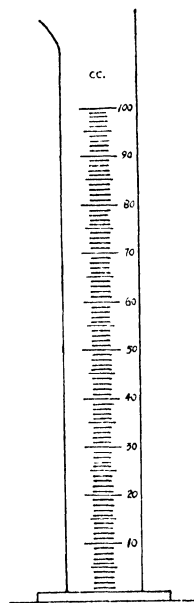


FIG. 80.
GRADUATED
CYLINDER

The rise of water in the cylinder measures the volume of the solid.

Height of water-level *before* adding solid
= c.cm.

Height of water-level *after* adding solid
= c.cm.

Therefore, *volume of solid* (water displaced)
= c.cm.

THE BURETTE

The *burette* is a long, narrow, graduated cylinder with a tap or spring clip at the bottom, designed* to *deliver* volumes of liquids more accurately than a graduated cylinder. We generally use 50 c.cm. burettes in the laboratory, graduated from the top downwards in tenths of a cubic centimetre (0.1 c.cm.), so that it is possible to estimate to one-tenth of a division (0.01 c.cm.). Examine a burette. Fill it with water through a small funnel and adjust the water-level to 0.00 c.cm, *after making sure that the jet below the tap is full of water.*

Show your teacher the burette adjusted to read 0.00 c.cm.

TO FIND THE VOLUME OF ONE DROP OF WATER FROM A BURETTE

Let fifty drops fall slowly into a test-tube. Then read the new water-level.

Volume of 50 drops = c.cm., therefore, volume of 1 drop = c.cm.

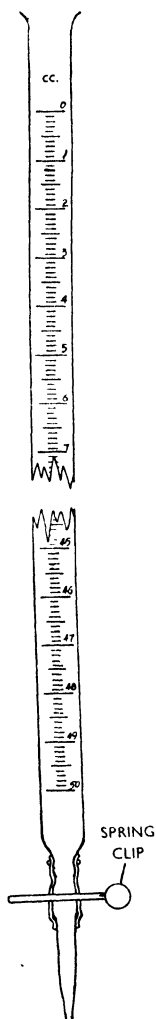


FIG. 81.
BURETTE

TO FIND THE VOLUME OF A LEAD SHOT

Adjust the water-level in your burette to 20.00 c.cm. Then count out fifty small lead shot and drop them into the burette.

Reading of burette *before* adding lead shot
=c.cm.

Reading of burette *after* adding lead shot
=c.cm.

Therefore, volume of 50 lead shot
=c.cm.

Therefore, average volume of one lead shot
=c.cm.

THE PIPETTE

The *pipette* is designed to *deliver* one fixed volume of liquid very accurately. Examine a pipette. Put the jet under some water in a beaker and suck air out of the pipette until the water rises above the mark on the tube. Then slip the *fore-finger* quickly over the top end as you remove your mouth. By carefully moving the finger, or by turning the pipette, allow water to escape until the surface is level with the mark on the tube. If the finger is now removed, the pipette will deliver the exact volume marked on it. In using a pipette, *be very careful not to damage the jet* or you will make the instrument useless. You will use a pipette again shortly.

MEASUREMENT OF WEIGHT

The weight of anything is the force (or pull) with which it is attracted by the Earth. To understand what this means, you will have to know something about the force with which the Earth attracts things, i.e. *the force of gravity*. In later lessons you will

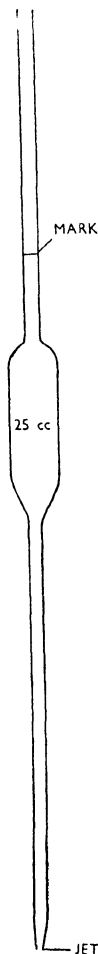


FIG. 82.
PIPETTE

learn more about *forces*, but for the present you can think of a force as being either a *push* or a *pull*. This *force of gravity* is a *pull*.

Sir Isaac Newton (1642-1727), after many experiments and observations, concluded:—

(i) That all objects attract each other to some extent.

(ii) That the force of attraction depends upon the quantity of matter in the objects (i.e. heavy objects, like the Earth, pull more strongly than smaller objects).

(iii) That the force of attraction depends upon the distance between the objects (i.e. the nearer together two objects are, the greater the pull between them).

This force of attraction between all objects is called the force of gravity.

The largest object which concerns us in our daily life is the Earth, and the quantity of matter in the Earth is very great indeed. Hence, although the pull between two blocks of iron hanging side by side, a few inches apart, is so small that we never notice it in everyday life, the Earth is so big that we always notice its pull on other objects. This pull of the Earth on an object is called *the weight of the object*.

If a block of iron is held on the hand, we feel it pressing downwards and we say that it is heavy, i.e. it has weight. If the hand is taken away, the block of iron, attracted by the Earth, falls to the ground. If there were nothing in the way, it would go on falling until it reached the centre of the Earth, where it would stop, having no longer any weight. Hence, when anything falls from a height, it moves along a straight line which, if produced, would pass through the centre of the Earth.

If we hang the block of iron from a spring, the extension of the spring measures the pull of the Earth, i.e. the weight of the iron. Hence a *spring balance* provides an easy way of measuring weight.

The pull between two objects is greatest when they are close together, hence a block of iron at the top of a mountain will *weigh less* than at sea level, since it is farther from the centre of

the Earth. If we travelled about the Earth's surface with a block of iron hanging from a spring balance we should find that the extension of the spring was not always the same, e.g. it would be greater at the Poles (where the Earth's diameter is less) than on the Equator* (where the Earth's diameter is greater). This difference in weight is never more than about 5 parts in 1,000, hence a spring balance is accurate enough for most of our elementary work.

If we used a scientific balance, which is an accurate pair of scales, and weighed a block of iron with brass weights at sea-level and then weighed it again up a mountain, we should find that the same brass weights exactly balance the iron at each place because, although the iron weighs less up the mountain, owing to its greater distance from the centre of the Earth, so do the brass weights, and in exactly the same proportion. Hence, for all accurate work in science, we use a balance (or pair of scales), and *compare* the weight of an object with that of our brass 'weights'. In this Science Course, however, we shall often use spring balances, which are accurate enough for some of our work and also much quicker to use.

See Appendix III for a description of a scientific balance and how it is used.

DENSITY

THE RELATION BETWEEN WEIGHT AND VOLUME

Compare a 1 lb. block of wood with a 1 lb. block of iron or brass. First make sure that their *weight* is the same by putting them on a balance or a pair of scales. Notice the big difference in their size or *volume*, as shown in the diagram. Hold the block of wood in one hand and the block of metal in the other.

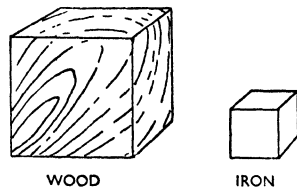


FIG. 83.

BLOCKS OF EQUAL WEIGHT

Do they both *feel* equally heavy ?.....

Although they are both of the same *weight*, the metal feels 'heavier' than the wood. It is clear that when we say that 'iron is *heavier* than wood', or 'cork is *lighter* than water', we are not speaking of the actual *weight* of particular pieces of iron, wood, or cork. We mean that if we took blocks of iron and wood *of the same size*, the iron would weigh more than the same volume of wood, i.e. we are thinking of *weight in relation to volume*. As it is confusing to use one word 'heaviness' in two different ways, we shall now use the word *density* for *weight in relation to volume*, e.g. iron is *denser* than wood, and cork is *less dense* than water.

On the metric system, *the density of a substance is the weight of one cubic centimetre of it*, i.e.

$$\text{DENSITY} = \frac{\text{WEIGHT}}{\text{VOLUME}}$$

For example, the density of water is 1 gram per cubic centimetre, and the density of mercury is 13.6 gm. per c.cm. The density of a substance is one of its most characteristic properties, hence the accurate measurement of density is of great everyday importance in every branch of science and engineering. We shall now find the density of some common materials.

Find the density of brass, copper, zinc, aluminium, and wood by weighing 1 cm. cubes of these materials.

- (a) 1 c.cm. of brass weighs.....gm., therefore density of brass =gm. per c.cm.
- (b) 1 c.cm. of copper weighs.....gm., therefore density of copper =gm. per c.cm.
- (c) 1 c.cm. of aluminium weighs.....gm., therefore density of aluminium =gm. per c.cm.
- (d) 1 c.cm. of zinc weighs.....gm., therefore density of zinc =gm. per c.cm.
- (e) 1 c.cm. of wood weighs.....gm., therefore density of wood =gm. per c.cm.

TO FIND THE DENSITY OF A SOLID

Find the volume of the given square wood block (by measurement and calculation) and then weigh it. Hence calculate the density of the wood.

Volume of block = by by = c.cm.

Weight of block = gm.

Therefore, density of wood = $\frac{\text{WEIGHT}}{\text{VOLUME}}$ = = gm.
per c.cm.

(If different kinds of wood are available, notice the different density of 'soft-woods' and 'hard-woods'.)

TO FIND THE DENSITY OF A LIQUID

Find the density of tap-water as follows. Weigh a 100 c.cm. beaker. Carefully measure out 50 c.cm. of tap-water with a pipette into the beaker, and weigh again.

Weight of empty beaker = gm.

Weight of beaker and 50 c.cm. of water = gm.

Therefore, weight of 50 c.cm. of water = gm.

Therefore, density of tap-water at ° C. = $\frac{\text{.....}}{50}$
= gm. per c.cm.

Find the density of the given sample of sea-water in the same way.

Weight of empty beaker¹ = gm.

Weight of beaker and sea-water = gm.

Therefore, weight of 50 c.cm. of sea-water = gm.

Therefore, density of sea-water at ° C. = $\frac{\text{.....}}{50}$
= gm. per c.cm.

¹ If you use the same beaker, there is no need to weigh it empty again.

THE EFFECT OF TEMPERATURE ON DENSITY

Solids, liquids and gases all *expand* as they get warmer, i.e. their volume becomes greater. But

$$\text{DENSITY} = \frac{\text{WEIGHT}}{\text{VOLUME}}$$

so that if the volume increases while the weight remains the same, the density will become less. Hence we must be careful to state the temperature at which the density was measured, especially when finding the densities of liquids and gases, e.g. at 4° C., the density of pure water is 1.000 gm. per c.cm.; at 30° C. it is 0.996 gm. per c.cm.; at 40° C. it is 0.992 gm. per c.cm.; and at 80° C. it is 0.972 gm. per c.cm. (Since solids expand less than liquids for the same rise in temperature, the effect of temperature on their density is so small that we need not take it into account in this Course.)

RELATIVE DENSITY† AND SPECIFIC GRAVITY

Density, the weight of unit volume, can be stated in any system of weights and measures, e.g. the density of water is 1 gm. per c.cm. on the metric system and 62.5 lb. per cu. ft. on the British system. This makes it difficult to *compare* the densities of two substances if they are given in different units. For example, if you are told that the density of alcohol is 0.8 gm. per c.cm. and that the density of kerosene is 50 lb. per cu. ft., you have to do a calculation before you can say whether alcohol is denser than kerosene. For most purposes, it is more convenient, instead of measuring the actual *density* of a substance, to *compare* its density with that of water.

The relative density (or specific gravity)† of a substance is its density compared with the density of water.

$$\begin{aligned}\text{RELATIVE DENSITY (OR SPECIFIC GRAVITY)} &= \frac{\text{DENSITY OF SUBSTANCE}}{\text{DENSITY OF WATER}} \\ &= \frac{\text{WEIGHT OF SUBSTANCE}}{\text{WEIGHT OF EQUAL VOLUME OF WATER}}\end{aligned}$$

(N.B.—Relative density (or specific gravity) is only a ratio,* hence we do not state any units, e.g. a substance of specific gravity=2, or S.G.2, is simply ‘twice as dense as water’.)

TO MEASURE THE SPECIFIC GRAVITY OF A LIQUID

Weigh a clean, dry, *specific gravity bottle*, together with its stopper. Notice that there is a small hole through the stopper to allow liquid to escape when the stopper is put in, so that the bottle can be filled exactly each time it is used. After weighing the empty bottle, fill it with water, put in the stopper, and weigh it again after drying the outside of the bottle very carefully. Find how much water the bottle holds by subtraction. Pour out the water, and wash the bottle with a few c.cm. of the given copper sulphate solution to remove the last of the water. Then fill the bottle with the copper sulphate solution, put in the stopper, dry the outside, and weigh again. (Return the copper sulphate solution to the stock-bottle after the experiment—do not pour it down the sink.)

HOLLOW STOPPER



FIG. 84. SPECIFIC GRAVITY BOTTLE

Weight of specific gravity bottle *empty* = gm.¹

Weight of specific gravity bottle *full of water* = gm.²

Therefore, *weight of water* = gm.²

Weight of specific gravity bottle *empty* = gm.¹

Weight of specific gravity bottle *full of copper sulphate solution* = gm.

Therefore, *weight of copper sulphate solution* = gm.³

But,

$$\text{SPECIFIC GRAVITY} = \frac{\text{WEIGHT OF SUBSTANCE}^3}{\text{WEIGHT OF EQUAL VOLUME OF WATER}^2} = \frac{\dots\dots\dots}{\dots\dots\dots}$$

Therefore, specific gravity of this copper sulphate solution is at ° C.

THE PRINCIPLE OF ARCHIMEDES

Archimedes (287-212 B.C.), a Greek mathematician and engineer who lived at Syracuse, in Sicily, was one of the greatest of the early scientists and he was one of the first to *apply* his knowledge to everyday problems. Hiero, the King of Syracuse, had given some pure gold to a goldsmith* to make a new crown. When the new crown was finished, it weighed the same as the original gold, but the king thought that the goldsmith had mixed some silver with the gold, and had stolen the rest of the gold. He ordered Archimedes to find out whether the crown was made of pure gold or not, without damaging it.

Archimedes was puzzled until, one day as he stepped into his bath, which was completely full of water, he realized that the overflow was equal to the volume of his body, i.e. he displaced an equal volume of water. He knew that gold was denser than silver and that equal *weights* of gold and silver would not displace equal *volumes* of water. So he put the new crown on one pan of a balance and added *pure gold* (lent by the king) to the other pan until the two sides balanced. He then put this equal weight of pure gold into a vessel which was completely full of water, and the gold displaced its own volume of water. He then took out the pure gold and put the crown in the water which was left in the vessel. *Some more water was displaced*, proving that the volume of the crown was greater than that of the same *weight* of pure gold, i.e. the *density* of the crown was *less* than that of pure gold and the goldsmith had cheated the king.

THE PRINCIPLE OF ARCHIMEDES

Later on, Archimedes also noticed that his body felt lighter in water than in air, and by careful reasoning he showed that there was an upward force acting on his body *equal to the weight of water he displaced*. This is now known as '*the Principle of Archimedes*' and it may be stated as follows:—

When an object is weighed in air and then in a liquid, there seems

to be a loss in weight. This loss in weight is equal to the weight of liquid displaced by the object.

Since it also applies to *gases*, a more general way of stating the principle is to say, '*When an object is completely surrounded by a fluid,* there is a force acting upwards on the object equal to the weight of fluid displaced*'. (The term *fluid* includes both liquids and gases—anything that *flows*.)

TO TEST THE TRUTH OF ARCHIMEDES' PRINCIPLE

Hang a solid object (e.g. a lump of metal, glass, or stone) by a piece of cotton thread from a spring balance and record its weight below. Take an *overflow can*, put a beaker under its side-tube and pour water into the can until it overflows into the beaker. When the water stops dropping from the side-tube, remove the beaker and in its place put an empty beaker which has been weighed on the spring balance. Then lower the solid, hanging from the spring balance, into the overflow can until it is completely surrounded by water (but *not* resting on the bottom). Read off the new weight of the solid from the spring balance. Then find the weight of the water, displaced by the solid, which overflowed into the weighed beaker.

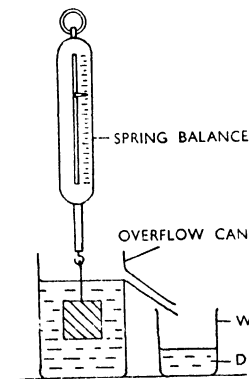


FIG. 85.
TESTING THE TRUTH OF
ARCHIMEDES' PRINCIPLE
W. Weighed Beaker
D. Displaced Water

Weight of solid
in water = gm.

Weight of solid
in air = gm.

Therefore,
seeming
loss in
*weight*² = gm.

Weight of beaker
and water = gm.

Weight of empty
beaker = gm.

Therefore, *weight*
of water dis-
*placed*¹ = gm.

Compare this loss in weight² of the object when surrounded by water with the weight of water displaced.¹ If they are the same, it shows that *when an object is first weighed in air and then in a liquid, there seems to be a loss in weight equal to the weight of liquid displaced.*

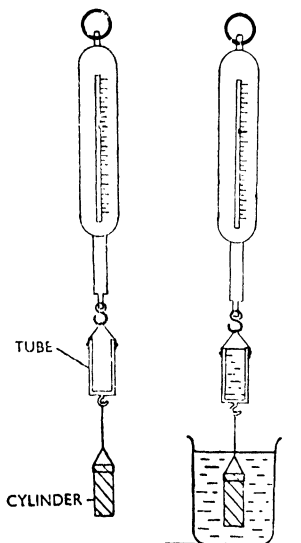


FIG. 86.
TESTING THE TRUTH OF
ARCHIMEDES' PRINCIPLE

Another way of testing the truth of this principle is to take a metal cylinder and a tube into which it fits exactly, and hang them from a spring balance as shown in the diagram.

Note the weight. gm.

Now put a beaker of water under the apparatus and lower the balance until the cylinder is surrounded by water.

What happens?

.

Carefully pour water into the tube until the balance reads the same as before.

How much water is needed for this?

What is the volume of this water?

.

What do you conclude from this?

FINDING SPECIFIC GRAVITY BY USING ARCHIMEDES' PRINCIPLE

Archimedes' Principle can be used to find relative density or specific gravity, since

$$\begin{aligned} \text{SPECIFIC GRAVITY OF SOLID} &= \frac{\text{WEIGHT OF SOLID}}{\text{WEIGHT OF EQUAL VOLUME OF WATER}} \\ &= \frac{\text{WEIGHT OF SOLID}}{\text{WEIGHT OF WATER DISPLACED}} \\ &= \frac{\text{WEIGHT OF SOLID IN AIR}}{\text{LOSS OF WEIGHT IN WATER}} \end{aligned}$$

Hence, to find the specific gravity of a solid, we have only to *weigh the solid in air, then in water, and divide its weight in air by the seeming loss of weight in water.*

TO FIND THE SPECIFIC GRAVITY OF A SOLID, USING ARCHIMEDES' PRINCIPLE

Hang the solid (e.g. a piece of metal, glass or stone) by cotton thread from a spring balance and weigh it, first in air, and then surrounded by water, as shown in the diagram.

Weight of solid
in air =gm.

Weight of solid
in water =gm.

Therefore, *loss*
in weight =gm.
=

But, S.G. = $\frac{\text{WEIGHT OF SOLID IN AIR}}{\text{LOSS OF WEIGHT IN WATER}}$

Therefore, S.G. of solid =
.....

TO FIND THE SPECIFIC GRAVITY OF A LIQUID, USING ARCHIMEDES' PRINCIPLE

If we weigh a solid, first in air and then in water, the seeming loss in weight is the weight of an equal volume of water. If we weigh the solid first in air and then in some other liquid, the loss in weight is the weight of an equal volume of the second liquid. Dividing one by the other we get the specific gravity of the second liquid. Find the specific gravity of the given common salt solution in this way, weighing a piece of glass (e.g. a large stopper) first in air, then in water, and then in the salt solution.

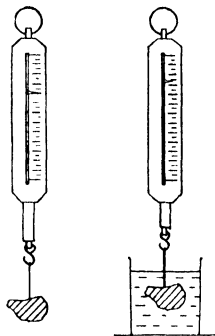


FIG. 87. FINDING THE SPECIFIC GRAVITY OF A SOLID OR LIQUID, USING ARCHIMEDES' PRINCIPLE

Weight of glass
in air =gm.

Weight of glass
in water =gm.

Therefore, *weight
of water
displaced* =gm.

Weight of glass
in air =gm.

Weight of glass
in solution =gm.

Therefore, *weight
of solution
displaced* =gm.

But,

$$\begin{aligned}\text{SPECIFIC GRAVITY OF SOLUTION} &= \frac{\text{WEIGHT OF SOLUTION}}{\text{WEIGHT OF EQUAL VOLUME OF WATER}} \\ &= \frac{\text{WEIGHT OF SOLUTION DISPLACED}}{\text{WEIGHT OF WATER DISPLACED}}\end{aligned}$$

Therefore, specific gravity of salt solution at° C. =
..... =

FLOATING

When an object is surrounded by water (or any other fluid) there are two forces acting on the object in opposite directions:— (a) its own weight acting downwards, and (b) a force equal to the weight of water displaced, acting upwards. If the downward force is greater than the upward force, then the object will *sink* to the bottom. If the object weighs less than the water it displaces, then the upward force due to the displaced water will push the object to the surface, and part of it will rise out of the water until the upward force is equal to its own weight. This is summed up in the *principle of floating*:—

A floating object displaces its own weight of the fluid in which it floats.

TO TEST THE TRUTH OF THE PRINCIPLE OF FLOATING

Float a test-tube upright in water by pouring into it enough sand to bring the mouth about an inch above the surface. Dry the outside of the tube, being careful not to lose any of the sand, and then weigh it. Record this weight below. Pour about

70 c.cm. of water into a 100 c.cm. measuring cylinder, and read off the volume accurately. Then lower the test-tube gently into the measuring cylinder and read off the new volume, holding the test-tube in the middle of the cylinder with your pencil.

Weight of test-tube and sand²
= gm.

Original volume of water in
cylinder = c.cm.

Volume with test-tube floating
in the water = c.cm.

Therefore, volume of water
displaced by test-tube
= c.cm.

Therefore, *weight of water displaced by test-tube*¹ = gm.

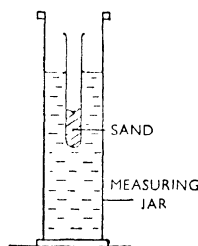


FIG. 88.
PRINCIPLE OF
FLOATING

If the weight of this water¹ is equal to the weight of the test-tube and sand² it shows that *a floating object displaces its own weight of the fluid in which it floats.*

THE FLOATING OF SHIPS

The last experiment explains the floating of ships. A ship floats at such a depth that the *weight of the ship* is exactly balanced by the upward force due to the *water displaced*. As it is loaded, the ship sinks a little deeper in the water so as to displace enough water to balance this extra load. A steel ship floats because it is hollow and the volume of water which it displaces is very much greater than the volume of the actual steel used in building the ship. Its *average density* is less than the density of water, so in displacing its own *weight* of water it displaces only a fraction of its total *volume*. The 'displacement'† of a ship is the weight of water she displaces when floating, i.e. her own *weight*. It is impossible to weigh a big ship directly, but it is fairly easy to find her volume below the water-line. This volume multiplied by the density of the water gives the weight of the ship, calculated from

her *displacement*. The ‘tonnage’† of a ship is the maximum weight of cargo she can carry, i.e. the difference between her *displacement* when empty and when fully loaded.

During the nineteenth century, ships were often overloaded until they floated too low to survive rough seas and were easily sunk in a storm. To stop the loss of sailors’ lives, a Member of Parliament named Plimsoll† succeeded in getting a law passed,

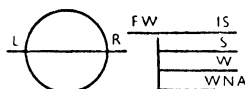


FIG. 89. PLIMSOLL MARK

in 1890, to stop this overloading of ships, and every British merchant ship now has a *Plimsoll Mark*, or *load-line*, on each side of the ship. In the diagram, ‘LR’ means that the load-line has been fixed by Lloyd’s Register* of shipping,

and this is the normal* summer load-line for sea-water.

The other marks to the right of the load-line show the maximum depth to which the ship may be loaded in (a) fresh water, ‘FW’, (b) the Indian Ocean in summer, ‘IS’, (c) summer in temperate* seas, ‘S’, (d) winter, ‘W’, and (e) winter in the North Atlantic, ‘WNA’, when rough seas make it necessary to provide an extra margin* of safety. Notice that more of the ship is below the surface in fresh water than in sea-water, because sea-water is denser than fresh water and the same upward force is produced by displacing a smaller volume of sea-water. The summer and winter marks are different because warm water is less dense than cold water.

Submarines† are ships whose average density can be controlled. By letting water into the tanks,* the average density of the submarine can be made a little greater than that of the surrounding water, and the vessel sinks. To bring the vessel to the surface, the water in the tanks is displaced by compressed air until the average density of the submarine becomes less than that of water. When a submarine is under water, it is impossible to keep its average density exactly the same as that of the surrounding water, and it is kept travelling at the required depth by using horizontal rudders.* A *fish* keeps its average density equal to that of the

surrounding water by altering the size of its *swim-bladder*, which contains air.

Airships and balloons (but not aeroplanes) depend on the same principle, and for an airship or balloon to rise in the air, the upward force due to the air displaced by the balloon must be greater than the total weight of the balloon.

HYDROMETERS

We have seen that the fraction of a floating object which is below the surface depends on the density of the liquid. The hydrometer,† an instrument for finding the specific gravity of a liquid very quickly, makes use of this fact.

TO SHOW THE PRINCIPLE OF THE HYDROMETER

A ‘*density-rod*’ is a very simple kind of hydrometer. It is a wooden rod, weighted at one end to make it float upright. It is usually 15 cm. long and of 1 cm. square section, and it is marked in centimetres from end to end. Put a density-rod in a cylinder of water and note the depth to which it sinks, i.e. the length of the rod below the surface.cm.¹ Since the area of its cross-section is 1 sq. cm., the *volume of water displaced* =c.cm.² and since the rod is *floating* in the water, the *weight of this water is equal to the weight of the rod*.

Dry the density-rod and then put it in a cylinder of salt solution. Note the depth to which it sinks.cm.³ Therefore, the *volume of salt solution displaced* =

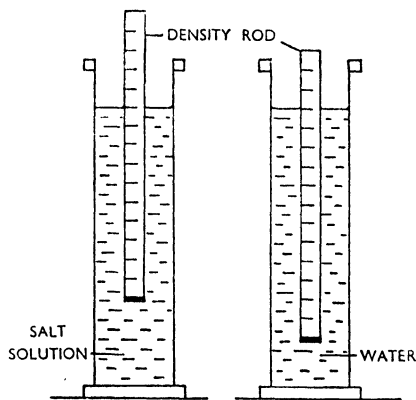


FIG. 90. SPECIFIC GRAVITY BY DENSITY ROD

c.cm.⁴ But since the rod is floating in the liquid, *the weight of this salt solution is equal to the weight of the rod.*

We have now found the *volumes* of water and salt solution which have *the same weight*, and from this we can easily find their specific gravities since

$$\text{WEIGHT OF SOLUTION DISPLACED} = \text{WEIGHT OF WATER DISPLACED}$$

i.e. volume of solution displaced \times density of solution = volume of water displaced \times density of water.

Therefore,

$$\frac{\text{DENSITY OF SOLUTION}}{\text{DENSITY OF WATER}} = \frac{\text{VOLUME OF WATER DISPLACED}^2}{\text{VOLUME OF SOLUTION DISPLACED}^4}$$

But

$$\begin{aligned} \text{SPECIFIC GRAVITY OF SOLUTION} &= \frac{\text{DENSITY OF SOLUTION}}{\text{DENSITY OF WATER}} \\ &= \frac{\text{VOLUME OF WATER DISPLACED}^2}{\text{VOLUME OF SOLUTION DISPLACED}^4} \\ &= \frac{\text{LENGTH OF ROD BELOW SURFACE OF WATER}^1}{\text{LENGTH OF ROD BELOW SURFACE OF SOLUTION}^3} \end{aligned}$$

Therefore, S.G. of salt solution = $\frac{\dots\dots\dots 1}{\dots\dots\dots 3} = \dots\dots\dots$ (at $\dots\dots\dots^\circ\text{C}.$)

PRACTICAL HYDROMETERS

With a density-rod, therefore, we can compare the density of a liquid with that of water, and the specific gravity of the liquid is easily found by dividing the length of the rod under water by the length of the rod under the liquid. A practical hydrometer, like the one shown in the diagram, works on the same principle, but it consists of a glass tube weighted at its bottom end with mercury or lead, so that it floats upright. To save any calculation, however, the glass tube contains a paper scale marked directly with specific gravities, so that when the instrument is put in pure water, it sinks until the surface of the water is level with the 1.000 mark on the scale. When put in a denser liquid, the hydrometer does not sink so deep, and the specific gravity of the liquid can be read

off directly on the hydrometer scale at the point where the stem cuts the surface of the liquid.

In everyday life, hydrometers are used for testing milk, for testing the acid in car batteries, and for finding the amount of alcohol in wines and spirits. Using a hydrometer, the specific gravity can be found very quickly, since it is only necessary to float the instrument in the liquid and read the specific gravity by the scale. To make the instrument more accurate, the glass tube containing the scale is made very thin, and so that the hydrometer shall not be so long as to break easily, hydrometers are usually made in sets for measuring different ranges of densities, one instrument leaving off where the next begins. Thus, a set of four hydrometers may read from 0·700 to 1·000; 1·000 to 1·300; 1·300 to 1·600; and 1·600 to 2·000. As all common liquids (except mercury) have specific gravities between 0·7 and 2·0, the decimal-point is usually left out of the figures on commercial hydrometers, so that the above set is marked 700 to 1000; 1000 to 1300; 1300 to 1600; and 1600 to 2000. If you see a bottle in the laboratory labelled 'AMMONIA—S.G.900', it contains a solution of ammonia gas in water of specific gravity 0·900.

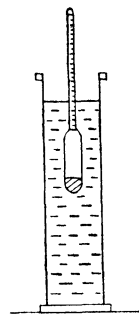


FIG. 91.
HYDROMETER

Use glass hydrometers to find the specific gravity of the following liquids:—

Specific gravity of *methylated spirit* at°C. =.....

Specific gravity of *saturated salt solution* at°C.=.....

Specific gravity of *saturated calcium chloride*†
solution at°C. =.....

Examine a *battery hydrometer*. When a *lead accumulator* (e.g. a car battery) is fully charged, the specific gravity of its sulphuric acid rises to over 1·20. If the specific gravity is less than 1·18 the battery needs re-charging. This is the best way

of testing a battery. A battery hydrometer can be made very small, since it is only marked from 1·100 to 1·250. ·

QUESTIONS

1. What instrument would you use to measure out 27·45 c.cm. of water ?
2. What is the length of a metre in inches ?
3. What is meant by the ' pitch ' of a screw ?
4. What is the greatest practical advantage of the Metric System ?
5. The names of many scientific instruments end in ' -meter '. What is the meaning of this word-ending ?
6. Write down the names of four instruments whose names end in ' -meter ', and say what they are used for.
7. What would be the best instrument to use for measuring the thickness of a safety-razor* blade ?
8. One inch = cm.
9. What is the relation between a litre and a kilogram ?
10. What is the relation between a litre and a metre ?
11. Define the British Unit of Length.
12. What is the name of the device used for estimating fractions of scale divisions on measuring instruments ?

APPENDIX I

GENERAL DIRECTIONS FOR SCIENCE CLASSES

1. ADMITTANCE TO SCIENCE ROOMS

No pupil is allowed in any Science Room unless a teacher is present.

2. USE OF LABORATORY MATERIALS

Caution. Laboratory materials are to be used only in the Science Rooms. They must be used only for the purpose approved by the teacher, and pupils are warned not to go beyond the directions of the teacher in any experiment. Nothing must be taken away from any Science Room. Remember that most chemicals* are poisonous, and that many of them eat away the skin, clothes and other materials by chemical action. It is therefore necessary to be very careful in using chemicals. Bottles should never be carried by the neck. Always be careful that the name on the bottle is *exactly* the same as that of the substance you require.

3. ACCIDENTS

Any cut, burn, chemical in the mouth, or other accident must be reported *at once* to the teacher. Prompt treatment will save you trouble and pain later. If you get any chemical on the skin or clothes, wash it off *at once* with plenty of water. Anything accidentally taken into the mouth you must spit out *at once* (*do not swallow it*) and the mouth must be washed out with plenty of water. If your clothes ever catch fire, *do not run about*, but roll on the floor until the fire-proof blanket* is brought. (Do not let this frighten you about practical work in science. Very few

people have such accidents, but it is always safer to ‘ *Be Prepared* ’ and to know what to do if accidents happen.)

4. CARE OF SCIENCE ROOMS

One of the most important things you will learn from your school Science Course is the value of cleanliness and tidiness in your practical work and also in your everyday life. You will expect to find the Science Rooms clean and tidy when you come to science lessons, therefore *you* must leave them equally clean and tidy for the next class after you have finished work. All apparatus* must be cleaned and put back in its proper place when practical work is over. Do not put bits of glass, corks, match-sticks and such articles in the drawers. Do not use burning pieces of paper for lighting your burner. Let hot articles cool before putting them away.

When you are using a burner, protect the bench* underneath with an asbestos sheet. If anything is too hot to hold in the fingers, put it on this asbestos sheet and not on the bare bench. If you drop any liquid on the bench, wipe it up with a *wet* duster. Solids (e.g. bits of paper, broken glass, match-sticks, etc.) must not be thrown in the sinks,* but must be put in the waste-boxes which are provided for this purpose. When you pour acids or other chemicals down the sinks, wash down with plenty of water so as to stop the chemicals from attacking the drains. When emptying gas-troughs (see p. 161), hold the trough well over the sink: do not let water run down the outside of the sink.

Turn off the water-taps and gas-taps when not in use so as to avoid waste. Turn down the flame when you are not going to use the burner for the next few minutes.

Your teacher will show you the proper way to remove the stopper from a bottle. Always see that you replace the stopper in the proper bottle. (Bottles and stoppers are often marked with a letter or number so that there should be no mistake.) Always pour out of the side *opposite to the label*.*

Any breakage or damage must be reported *at once*.

APPENDIX II

SCIENCE APPARATUS

(The 'Tools' used in the Laboratory)

BUNSEN BURNER

We nearly always use a Bunsen burner when we want to heat anything in the laboratory.* It gets its name from its inventor, the German chemist* Bunsen and it burns coal-gas or petrol-gas (a mixture of petrol vapour† and air). If we unscrew the burner-tube, we see a small jet* in the base of the burner, through which the gas passes. A tap controls the flow of gas. If we put back the burner-tube, close the *air-holes*, and light the gas, we get a white or yellow flame (a luminous* flame) which is not very hot, and which is rather smoky. If we open the air-holes gradually we notice that the flame becomes *non-luminous*, cleaner, and much hotter. This is the *Bunsen flame* we use for most of our work, and you must practise controlling the gas and air until you can get this hot, clean flame. A large *wind-shield* is used for sheltering the flame from the wind when the windows are wide open.

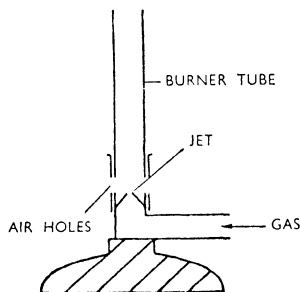


FIG. 92. BUNSEN BURNER

TRIPOD STAND

The *tripod stand* is a firm and steady support, of fixed height. Having three legs, it always stands firmly on any surface, even if its three feet are not level. A *flame-steadier* is a tripod stand combined with a small wind-shield.

RETORT STAND

A *retort† stand* provides support at different heights by means of movable *retort rings* and *retort clamps* which are fixed to the stand by *cross-head clamps*. A retort stand is not so steady a support as a tripod.

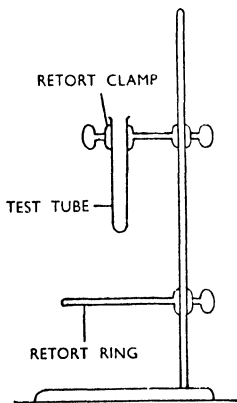


FIG. 93.
RETORT STAND

WIRE GAUZE

A *wire gauze* is made of tinned iron wire and is put between the burner and glass or porcelain* vessels to spread out the heat of the flame evenly over the bottom of the vessel. This lessens the risk of the vessel's breaking.

SAND BATH

A *sand bath* is a shallow iron dish, filled with sand, which is put between the flame and the vessel which is being heated. A sand bath serves the same purpose as a wire gauze, but gives more protection and allows more gentle heating.

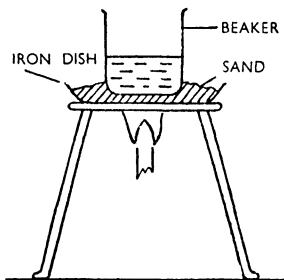


FIG. 94. SAND BATH

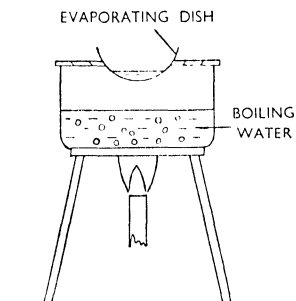


FIG. 95. WATER BATH

WATER BATH

A *water bath* is a vessel in which water is boiled over a burner, and any other vessel which is to be heated *very gently* is put on

top of the water bath, where it is heated by the steam from the boiling water. This gives even more gentle heating than the sand bath, because the temperature cannot rise above 100° C. (the temperature of boiling water).

FIRECLAY TRIANGLE

The *fireclay triangle** is a support for a small article like a crucible when it is to be heated very strongly in the Bunsen flame. It is an iron wire triangle covered with fireclay (or pipeclay) tubes.

CRUCIBLE AND LID

A *crucible* is a small vessel made of thin *porcelain*.* It can be heated directly by the flame, without using a wire gauze or sand bath.

EVAPORATING DISH

An *evaporating dish* is a porcelain vessel used chiefly for evaporating* liquids. It is heated over a wire gauze, over a sand bath, or over a water bath, according to the degree of heating required.

FLASKS AND BEAKERS

Flasks and *beakers* are glass vessels in which liquids can be heated. The glass is usually protected from the direct flame by a wire gauze or a sand bath. Flasks can be fitted with corks, beakers cannot.

TEST-TUBES

Test-tubes are thin glass vessels for small-scale experiments when only small quantities of material are required. They may be heated directly by the flame if they are kept moving, and if the flame is not allowed to touch the glass above the level of the liquid in the tube. Dirty test-tubes are cleaned with the *test-tube brush*, and are left to dry in the *test-tube stand*. Solids which are to be strongly heated are put in *hard glass test-tubes*. 'Hard'

glass is *potash glass*,† which has a higher *melting-point* (i.e. it is 'harder' to melt) than ordinary 'soft' glass, which is *soda glass*.†

CRUCIBLE TONGS

Crucible tongs are for holding hot crucibles and lids, but *not* for holding test-tubes. (If a test-tube becomes too hot to hold with the fingers, make a test-tube holder from a piece of neatly folded paper.)

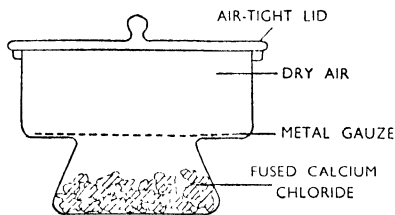


FIG. 96. DESICCATOR

DESICCATOR

A *desiccator* is a thick glass vessel fitted with a large, air-tight lid. The lower part contains fused calcium chloride, a substance which takes up water-vapour. This keeps the air inside the desiccator quite dry, and anything put inside the desiccator will remain dry. Inside some desiccators is a piece of paper which has been soaked in cobalt chloride solution and then dried. When the air inside the desiccator is quite dry, the cobalt chloride paper is *blue*, but if the air becomes damp, then the paper turns *red*. (This means that fresh calcium chloride is needed or that the lid of the desiccator has been left open.)

WASH BOTTLE

A *wash bottle* is a glass flask or bottle fitted with a cork carrying two bent glass tubes. One of these tubes is fitted with a jet, while the other is used to blow in air from the mouth when a stream of water is needed from the jet. A

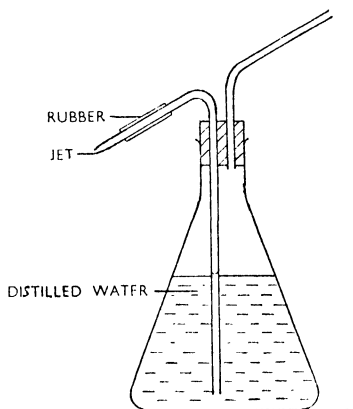


FIG. 97. WASH BOTTLE

wash-bottle usually contains *distilled water* (i.e. pure water) and is a convenient means of supplying small quantities of water. Your teacher will show you how to get (a) a more rapid stream, (b) single drops of water, from a wash bottle.

CORK BORERS

Cork borers† are brass or steel tubes with one end sharpened for boring corks. The cork which is to be bored is first softened by rolling it on the floor under the foot. A cork borer is then chosen which is *slightly smaller* than the tube for which the cork is being bored. The cork borer is wetted and screwed into the cork, starting from each end in turn.

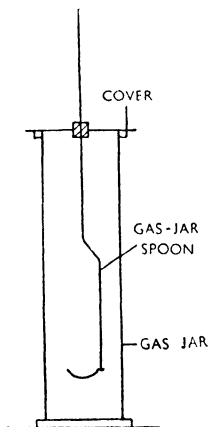


FIG. 98. GAS JAR

GAS TROUGH

The *gas trough*† is a large earthenware* trough used for collecting gases over water in *gas-jars* of thick glass. A *gas-jar stand* is usually put in the gas trough for supporting the gas-jar. When full, the mouth of the gas-jar is closed by a glass *gas-jar cover*, which is roughened on one side.

OTHER APPARATUS

The *blow-pipe* is used for giving a small, but very hot, flame. The *gas-jar spoon* is for holding substances which are to be burnt in a jar of gas. The *triangular file*† is for scratching glass tubes and rods before breaking them off, while the *round file* is for enlarging holes in corks. The *pestle*† and *mortar*† are for crushing and powdering solids. The *spatula*† is for picking up solid chemicals.

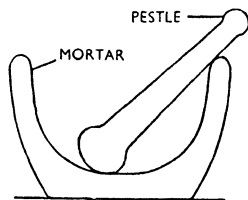


FIG. 99.
PESTLE AND MORTAR

APPENDIX III

WEIGHING

In everyday life, many things are bought and sold by weight, hence scales, spring balances and other instruments for weighing are common objects. In science lessons, too, we have to do a lot of weighing, and as we usually want to weigh small things accurately we use especially delicate and accurate weighing instruments. In our early work in science, we shall weigh with spring balances as far as possible, so as to save time.

THE SPRING BALANCE

The spring balances we shall use for much of our work consist of a fine spring, fixed at its upper end, and with a scale-pan† hanging from its lower end. When an object is put on the pan the spring stretches, and by measuring how far it stretches we can measure the weight of the object.

RULES FOR USING DELICATE SPRING BALANCES

(1) The spring balance is a very delicate instrument and must always be handled *very carefully*.

(2) The only part of the balance you may touch is the pan.*

(3) Do not let go of the pan suddenly, but hold your left forefinger against it while you put anything on and while you take anything off the pan.

(4) See that the spring is hanging freely in the middle of the glass tube. (If it touches the sides anywhere, tell the teacher and he will put it right with the levelling-screws.)

(5) See that the scale-reading is zero when there is nothing on the pan, sighting on the metal disc.* Raise or lower your head until the disc is in line with its reflection in the mirror.* Your

eye is then on exactly the same level as the disc. Keep your eye in this position while you read off the weight on the paper scale. (If the unloaded reading is not zero, tell the teacher and he will put it right.)

(6) See that the object to be weighed is *clean, dry* and *cool*. Steadying the pan with your left forefinger, put the object in the *middle of the pan* and lower the pan gently, steadying it underneath with your finger until the spring is fully stretched.

(7) When you have finished weighing, hold down the pan with your left forefinger while you remove the object, and allow the pan to rise *gently* to its original position.

(8) If there is a wind, close the glass door before reading the weight.

(9) Use decimals and *not* fractions.

TEACHERS' NOTE.—Delicate spring balances of this type are very useful indeed. They can be made very easily and for a very small cost. The author has had fifteen of these 'home-made' balances in use by over 500 boys for two years and they have given every satisfaction. A beginner can be taught to weigh to 0.01 gm. in a few minutes, and it becomes unnecessary to teach the complicated technique of accurate weighing with a chemical balance until a later stage, e.g. during the section on 'Measurement', when his practical skill is greater. Although the maximum load of these spring balances is

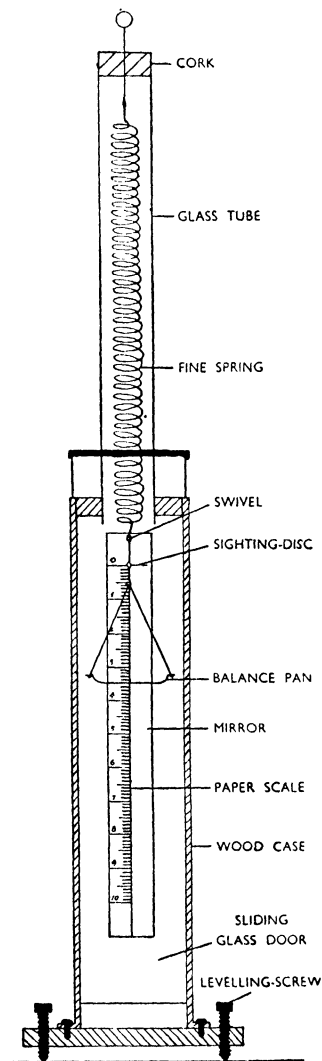


FIG. 100.
DELICATE SPRING BALANCE

THE SCIENTIFIC BALANCE

Examine a scientific balance and notice that it consists of a beam† and two *scale pans*, the beam being balanced at its mid-point on a *knife-edge*. The scale-pans also hang on smaller knife-edges near the ends of the beam by means of stirrups.† When the balance is not in use, the beam does not rest on its knife-edge but on the *beam supports*, while the scale-pans rest on the base-board. When the handle in front of the base-board is turned to the right, the beam is raised by the arrangement shown in the diagram (Fig. 102). The beam must always be raised and lowered *gently* to avoid damaging the knife-edges, and nothing must be put on, or taken off, the scale-pans unless the beam is lowered. The small adjusting-screws† at the ends of the beam are for adjusting the balance when one side is slightly heavier than the other. The *levelling-screws* at the front corners of the base-board are for setting the balance perfectly level, with the pillar† vertical, as shown by the plumb-line.†

small, it is surprising how many quantitative experiments can be done with them, and how much time is saved. Using the chemical balance, the beginner is so engrossed in the technique of weighing that, in an experiment which involves several weighings, he often loses sight of the real object of the experiment.

The spring consists of about 80 turns of No. 32 S.W.G. phosphor-bronze wire,¹ closely wound on a three-eighths in. iron rod and then tempered by passing through a Bunsen flame until it changes colour. The top end is fastened to a few inches of stiff brass wire passing through a cork, and the lower end is attached by a small swivel (as used for fishing-tackle) to a short piece of No. 20 S.W.G. aluminium wire threaded through the centre of a half-inch circular disc (cut from No. 22 or 24 S.W.G. aluminium sheet). A small piece of soft wax holds this disc horizontal and makes final adjustments easy. The pan, which is suspended by three threads, is a 2.5 in. disc of No. 24 S.W.G. aluminium sheet. The base of the instrument is a piece of 7-ply wood, 12 in. by 10 in., provided with three levelling-screws. On this base is mounted a 3-ply box 4.5 in. square and 24 in. high, with a sheet of glass sliding in grooves in front. The spring is supported inside a glass tube, 18 in. by 1 in. In the back of the case is a piece of mirror, 15 in. by 2 in., with a 1 in. strip of paper gummed on one half. The balance is calibrated by marking the levels of the disc with no load and with 10 gm. on the pan, and then dividing this distance into 100 equal parts.

I am indebted to my friend Mr T. L. Green, of Bristol University, for drawing my attention to this use of phosphor-bronze springs and for many practical suggestions embodied in the above design.

¹ Phosphor-bronze wire can be obtained from P. Ormiston & Co., 79 Clerkenwell Road, London, E.C.1, and 4 oz., costing about eighteen pence, will make dozens of balance-springs.

For accurate weighing, a balance is kept in a *balance-case* fitted with a sliding glass door in front to keep out currents of air when the beam is swinging. It is important to raise and lower the sliding door *gently*, so as to avoid damaging the balance. The door is always kept closed when the balance is not in use.

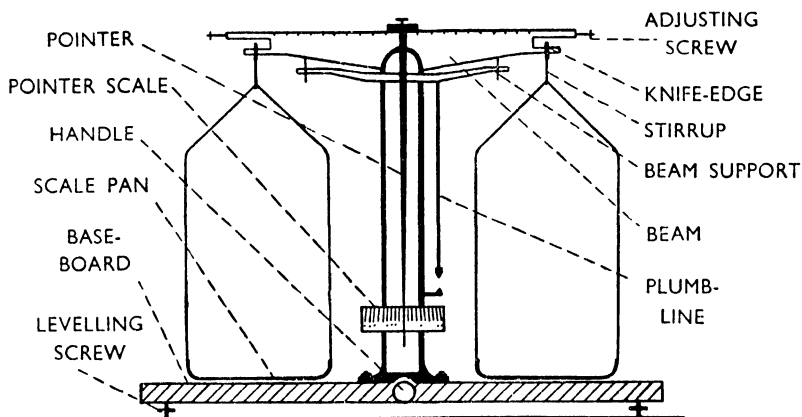


FIG. 101. THE BALANCE

THE WEIGHTS

The weights used for scientific work are those of the Metric System. The unit we use is the gram, and weights are always written down as grams and *decimals* of a gram. To save time and trouble, each weight has its own place in the box, and you must always put each weight back in its proper place after use. The weights must always be kept the right way up and the right way round so that their numbers can be read easily. Always lift the weights with the forceps and *never* with the fingers: fingering would soon change their weight and make accurate weighing impossible. (One of the quickest ways of judging the standard of work in a school laboratory is to examine the balances and weights: if these are badly kept, then the standard of all the practical work is almost certainly low.)

Examine a box of weights and notice that the weights are of two kinds, the heavier ones (1 gm. and upwards) being made of brass, and the smaller ones (less than 1 gm.) of nickel, aluminium, or silver. These smaller weights may be marked either (a) in decimals of a gram, i.e. 0.5 gm., 0.2 gm., 0.1 gm., 0.05 gm.,

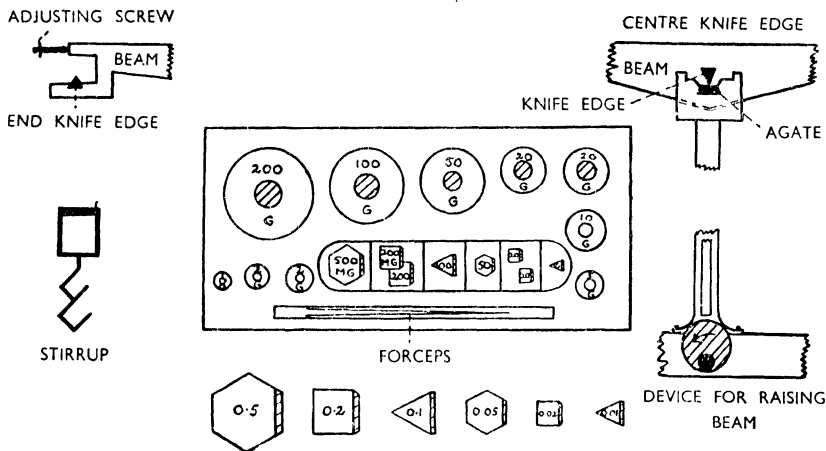


FIG. 102. BOX OF WEIGHTS

0.02 gm., 0.01 gm., or (b) in milligrams,† i.e. 500, 200, 100, 50, 20, 10. The latter system has the advantage that the smallest weights bear the smallest number of figures. To remove the piece of glass which covers the smaller weights, press down with your left forefinger on the left-hand end of the glass, and then remove it with your right hand. (Forceps must *not* be used for this.) To pick up the brass weights (1 gm. and upwards), hold the forceps with their points *upward*. For the smaller weights, turn the points *downward* and pick up by the upturned corner of the weight.

It is important to realize that a scientific balance is a very delicate instrument which is easily damaged unless very carefully handled. If you are to weigh accurately and without damaging

the balance or weights in any way, you must learn the following *Rules for Weighing* and carry them out whenever you use a balance. By following these rules you will learn to weigh quickly and accurately. Every trained scientific worker throughout the world uses this kind of balance in this way.

RULES FOR WEIGHING

(A) THE BALANCE

(1) See that the base-board is level and that the pillar is upright by looking at the plumb-line. (It is usual for the three feet of a balance to rest in small holes in the bottom of the balance case. If the balance is always kept in this same position it will not be necessary to readjust the levelling screws every time the balance is used.)

(2) See that the stirrups are resting on their knife-edges and that the centre of the beam is in place over the centre knife-edge.

(3) See that the balance is accurate, i.e. gently raise the beam and see whether the pointer swings an equal number of divisions on each side of the middle line on the pointer-scale. (If it does not, tell your teacher. Do not try to put it right yourself.) If your balance is in a case, nearly close the door, leaving an opening wide enough to put your hand through to turn the handle—unless the handle is outside the balance case.

(4) Gently lower the beam before putting anything on, or taking anything off, the scale-pans.

(B) THE OBJECT TO BE WEIGHED

(5) See that the object to be weighed is *clean*, *dry* and *cool*. Chemicals must not be put on the bare scale-pan.

(6) Put the object to be weighed in the middle of the *left-hand scale-pan*.

(C) THE WEIGHTS

(7) Lift the weights with the *forceps*, and *never* with the fingers. Put them either on the right-hand scale-pan or in the box, *nowhere else*.

(8) Put the weights on the *right-hand pan*, the right side up and the right way round, so that their numbers can be read easily. Keep the biggest weights in the middle of the pan.

(9) Start with a weight which is too big. Then *lower the beam*, remove the weight, and try the next smaller weight, thus working through all the weights one by one until the pointer swings an equal number of divisions on each side of the middle line on the pointer-scale when the balance-case is closed.

(10) Add up the weights on the pan and write down the total in your book. Check the weights by noting the empty spaces in the box. Then return the weights to the box in the same order, starting with the biggest. Add up the weights once more as you put them back in the box (being careful to put them the right side up and the right way round). In this way, you check the weight three times. (The commonest mistakes in weighing are made in counting the weights.)

All these instructions sound very complicated, but they are easily remembered after a little practice. The balance is the most delicate and accurate measuring instrument you will use in this science course and it is worth while learning to use it properly.

APPENDIX IV

ACCURACY

A very important part of your practical training during this Science Course is the proper use of figures in stating the results of your experiments. First of all, you must *always use decimals* and not fractions. In using decimals for practical purposes, you must learn the proper use of 0's. Many people think that 1 in., 1.0 in., 1.00 in., and 1.000 in., all mean the same thing, and that the 0's do not matter. They *do* matter. 1 in. means a length greater than 0.5 in. and less than 1.5 in., and that the length is accurate only to the nearest inch, i.e. it was measured very roughly, possibly from the width of a finger. 1.0 in. means a length greater than 0.95 in. and less than 1.05 in., and that the length is accurate to one-tenth of an inch, i.e. the length was measured more carefully, using a ruler marked in inches and tenths of an inch. 1.00 in. means a length greater than 0.995 in. and less than 1.005 in., and must have been measured still more carefully, probably with the *vernier calipers* (which you will use later). 1.00 in. is accurate to one-hundredth of an inch. 1.000 in. means a length greater than 0.9995 in. and less than 1.0005 in., i.e. the length is accurate to one-thousandth of an inch and was probably measured with a *screw-gauge* (which you will use later).

Notice that every figure has a definite meaning and tells us the *degree of accuracy* of the measurement. To take another example:—25 gm. is the sort of result you could get by weighing on a cheap 100 gm. spring balance, when the pointer is between 24 and 26, but nearer to 25 than either. This figure has an accuracy of 1 part in 25. On the other hand, 25.0000 gm. shows that the weighing was done very carefully indeed, on a very delicate and expensive scientific balance, using a very accurate

set of weights. 25·0000 gm. has an accuracy of 1 part in 250,000, because this figure means that the weight is between 24·9999 gm. and 25·0001 gm., but nearer to 25·0000 gm. than either. This represents a very high degree of accuracy: about the same as that of a clock which gains or loses one second in three days.

You must always be careful, therefore, never to put more figures in your result than you are sure about, e.g. in your first exercise on the measurement of length, using a ruler marked in inches and tenths, and also in centimetres and millimetres, if you find that a line 7·00 in. long measures 17·8 cm., do not say, 'Therefore, 1 inch=2·542857 cm.' This would be telling a *lie*, because you are pretending that you can measure more accurately with an ordinary ruler than a very highly trained and skilled scientist using the finest measuring instruments in the world ! Using a ruler, you cannot be sure of more than the first three figures, so leave your result as, '1 inch=2·54 cm.'

When working out results from actual measurements, the degree of accuracy of your result must be similar to the degree of accuracy of your measurements. Remember that 'the strength of a chain is the strength of its weakest link',* e.g. if you measure the sides of a rectangle and find them to be 2·34 in. and 1·23 in., multiplying these two numbers together you get 2·8782, but this figure is accurate to 1 part in 28,782 while your actual measurements were accurate to 1 part in 234 and 1 part in 123. So the last two figures of your product 2·8782 are worthless and must be left out if your result is to be a true statement.

In leaving out figures of whose accuracy you are doubtful, *if the first figure to be left out is a 5 or over, add 1 to the last figure kept in your result.* The area of the above rectangle, therefore, should be given as 2·88 sq. in. (This result has a degree of accuracy of 1 part in 288, which is similar to the degree of accuracy of your measurements.)

Notice that 'the number of decimal places' in a result is not the same thing as its 'degree of accuracy', e.g. 0·5 has the same degree of accuracy as 0·05 or 0·005, i.e. 1 part in 5. Hence it is

the number of significant figures* that matters in practical work and not the number of decimal places. As a rough guide, most of your final results in the practical work of this science course should be given to not more than *three significant figures*, as this represents the highest degree of accuracy you are likely to reach in most of your experiments. In counting the number of significant figures, take no notice of 0's before the decimal point or before the first significant figure, e.g. 5·6, 0·56, 0·056, 0·0056 and 0·00056 all have two significant figures. If your result comes out exactly 0·56 in. and your measurements justify* three significant figures, then add a 0 and give your result as 0·560 in. This shows that the measurement is accurate to one-thousandth of an inch.

You will also notice that when a number is less than one, we always put a 0 in front of the decimal point, e.g. 0·5 in., or 0·234 gm. This is very useful in drawing attention to this important little dot, especially during practical work, when you are doing an experiment and recording results at the same time (a very different business from sitting quietly at a desk in an arithmetic lesson). Practical men, whose living depends on not making mistakes with their figures, always use this 0 in front of the decimal point.

Note. The student should not part with this book. In studying Books II-IV he will want to refer back to the Glossary and the List of Technical Terms.

LIST OF TECHNICAL TERMS

(Referring to their first appearance)

accumulator, 104	burette, 135	clamp, 42	electrolysis, 108
acetylene, 54	buttress root, 85	clay, 36	element, 22
acid, 50		Clematis, 90	energy, 29
adjusting screw, 164	calcium, 22	cob, 68	evaporating dish, 26
air-root, 87	calcium carbide, 37	cobalt chloride, 43	
alcohol, 5	calcium chloride, 153	Coco-yam, 94	felspar, 35
alkali, 51	calcium chloride, fused, 11	Colocasia, 94	Ferns, 94
Almond, 86	calcium hydroxide, 52	combustion, 6	Ficus elastica, 85
aluminium, 22	calcium oxide, 52	complex, 31	fibrous-root, 85
ammonia, 114	calipers, 128	compound, 32	filter pump, 11
anhydrous, 42	Calopogonium, 92	concrete, 24	fireclay, 13
Antigonon, 89	Canna, 94	copper, 12	Flame tree, 85
argon, 17	carbon, 18	copper sulphate, 28	flask, 2
Arrowroot, 94	carbon cycle, 61	corm, 93	fruit, 66
asbestos, 11	carbon dioxide, 15	Cotton, 85	furlong, 122
atmosphere, 15	carbon disulphide, 33	Cow-pea, 75	
axil, 65	carbonic acid, 51	Cress, 76	gas trough, 161
	carmine, 81	Crinum, 93	gauze, 33
bacteria, 18	Carpet grass, 92	crucible, 12	Ginger, 94
bakelite, 24	Carrot, 88	crystal, 41	Gloriosa, 89
Balsam, 63	Cassava, 88	cubit, 121	gold, 36
Bamboo, 85	Cassutha, 91	Cucumber, 89	gram, 123
Banana, 96	catalyst, 48	Cuscuta, 91	granite, 35
Banyan, 87	caustic soda, 51	decimetre, 124	gravity, 75
base, 52	Ceiba, 85	dekametre, 124	gum, 38
battery, 104	cellophane, 82	density, 30	gunpowder, 36
beaker, 1	centigrade, 40	„ relative, 142	hectometre, 124
beam, 164	centimetre, 123	desiccator, 10	helium, 17
Bean, 67	Centrosema, 92	di-cotyledon, 71	honey, 66
Beetroot, 88	chalk, 39	Diesel-oil, 106	hydrate, 42
bell-jar, 7	charcoal, 36	digit, 122	Hydrocotyle, 92
bladder, 82	chlorine, 22	displacement, 149	hydrochloric acid, 51
Bougainvillea, 90	cholera, 103	Dodder, 91	hydrogen, 17
brass, 35	chromium, 15	dynamo, 29	hydrogen chloride, 115
breathing-root, 87	circumference, 125	dysentery, 103	hydrogen oxide, 113
bud, 65		electro-plating, 15	
bulb, 93		electrode, 107	
Bunsen, 2			

hydrogen sulphate, 114	magnesium sulphate 115	palm oil, 114	Rattan, 90
hydrogen sulphide, 37	magnet, 27	paraffin, 26	rectangle, 133
hydrometer, 151	Maize, 68	parallel-gram, 133	retort, 113
hydroxide, 42	manganese dioxide, 47	parasite, 91	rhizome, 93
	Mangrove, 87	parchment-paper, 82	Rice, 71
Imperata, 94	Melon, 89	Passion flower, 89	rod (measure), 122
Imperial System, 122	mercuric oxide, 26	Pea, 71	root-cap, 74
iodine, 23	mercury, 7	Pepper, 91	rootstock, 93
iron, 8	methyated spirit, 5	pestle, 161	root-system, 67
iron, galvanized, 15	metre, 123	petrol, 6	Rubber-tree, 86
iron chloride, 115	Metric System, 122	petroleum, 36	runner, 92
iron oxide, 32;	mica, 35	petroleum jelly, 14	
magnetic, 52	micrometer, 131	phosphoric acid, 51	salt, 37
iron sulphide, 34	micro-projector, 41	phosphorus, 7	sand, 36
	microscope, 18	phosphorus pent-oxide, 51	sap, 82
jelly, 14	Millet, 85	Pineapple, 96	saturated, 39
	milligram, 166	pipette, 135	scale-pan, 162
kerosene, 5	millimetre, 123	pillar, 164	scar, 67
kilogram, 123	Mimosa, 90	pitch, 131	screw-gauge, 131
kilometre, 124	Mistletoe, 91	Plantain, 96	Screw-pine, 86
	mono-cotyledon, 71	platinum, 23	Sensitive plant, 90
Lalang, 94	Morning Glory, 89	Plimsoll Mark, 150	shellac, 38
Lantana, 90	mortar, 33	plumb-line, 164	shoot, shoot-system, 67
lead, 23	moss, 50	pod, 67	silicon, 22
Lily, 93	nectar, 66	Poinciana, 85	Silk-cotton, 85
Lily, climbing, 89	neon, 17	pole, 122	silver, 23
Lime (plant), 85	nichrome, 25	potash glass, 160	skeleton, 66
lime, slaked, 39	nickel, 15	potassium, 22	soda glass, 160
limestone, 39	nitre, 36	potassium chlorate, 46	soda, washing, 37
lime-water, 6	nitric acid, 109	potassium hydroxide, 116	sodium, 22
linseed, 38	nitrogen, 15	potassium nitrate, 38	sodium carbonate, 42
litmus, 50	Onion, 93	Potato, 83	sodium chloride, 37
litre, 3, 123	Orange, 85	Potato, Sweet, 92	sodium hydroxide, 116
Loranthus, 91	Orchid, 74	prism, 134	sodium oxide, 51
loud speaker, 29	ore, 36	Prop-root, 86	solder, 35
	osmosis, 81	Pumpkin, 89	soot, 18
magnesium, 12	osmotic pressure, 82	pyramid, 134	span, 121
magnesium chloride 115	oxidation, 53		spatula, 161
magnesium hydr-oxide, 51	oxygen, 15	quartz, 35	specific gravity, 142
magnesium oxide, 32	palm (measure), 122	quick-lime, 6	Spinifex, 92
	Palm (tree), 71		spore, 18
		Radish, 88	Squash, 71
		radius, 125	starch, 17

GLOSSARY

(Simple definitions of general words in the text which are not included in the standard vocabulary on which the Course is based.)

absorb, take in or suck up, 79

accurate, exact, 3

acute (angle), (angle of) less than 90° , 65

agriculture, science of cultivation of the soil, 122

analyse, find out the *elements* of, 46

apparatus, machines, tools, vessels, etc., required for doing something, 11, 156

approximate, not exact, 22

arrow, \longrightarrow , 36

axle, bar on which a wheel turns, 126

balloon, air-tight bag filled with a gas lighter than air, 17

ball-bearings, small steel balls on which e.g. a bicycle wheel turns, 128

bench, a strong work-table, 156

blanket, large woollen bed-covering, 155

bore, make a hole in, 83, 161

bubble, ball of liquid enclosing air, etc., 1

candle, a stick of wax, etc., for giving light (see Fig. 3), 4

chemical (*n.*), any substance obtained by or used in chemistry, 155; (*adj.*) of or made by chemistry, 20

chemist, person skilled in *chemistry*, the science of the *elements*, 7, 157

circulation (of the blood), movement of blood to and from heart, 53

clasp, hold closely, 91

classify, *classification*, arrange(ment) in classes, 21

cling, stick on (to), 81

clip, thing made to hold articles together, 2

coil, length of wire, rope, etc., arranged in circles, 25

column, long upright cylinder of stone, etc., supporting building; anything of that shape, 82

combine, join together to form a compound, 10

compress, make smaller by pressure, 24

concentrated, (liquid) made very strong, 111

conclude, *conclusion*, judge(ment), 8, 12

condense, reduce from vapour to liquid

conduct, guide, lead, form a channel for, 108

constituents, parts making up the whole, 16

correspond, agree in size, be similar, 122

crude, in a natural or raw state, 36

crust, outer part of the earth, hard outer part of bread, 22

cubic, to do with a solid with six equal square faces or sides; *cubic centimetre*, volume of cube whose edges are one centimetre long, 123
cylinder, solid or hollow object sh. ped like a roller (see Fig. 80), 3
cycle, complete set of events which repeats itself, 61
decimal, of tenths or ten, 124
decompose, decay, 21
demonstrate, describe and explain by help of experiment, etc., 23
define, give exact meaning of, 122
definite, with exact limits, *distinct*, 23
design, plan, 136
device, invention, 129
dew, tiny drops of water *condensed*, 5
diagram, simple outline drawing, 2, 164
diameter, line drawn across circle through its centre, 127
dilute, reduce in strength, e.g. by adding water, 16
disc, thin circular plate, such as a coin, 162
display, show, 65
dissect, cut up (animal, plant), to examine, 68
distil, make pure by turning into vapour and cooling into liquid again, 36
distinct, plain, separate, unlike, *definite*, 3
drain (v.), carrying off water by a channel or *drain* (n.); *drainage* (n.), what has been drained, 75, 99
dye, colouring material, 50
e.g. (L. *exempli gratia*), for example.
earthenware, article of baked clay, 161
elbow, outer part of middle joint of arm ; corner or bend shaped like elbow, 121
equation, statement of the equality of two quantities (for example $9+3=12$), 37
equator, line on map circling the earth, halfway between the two Poles, 139
equivalent, equal in value (to), 124
essential (n.), necessary quality or part that makes a thing what it is ; (adj.) necessary, 16
estimate (v.), form a judgement of number, amount, etc. ; (n.) quantity thus arrived at, 135
evaporate, change into vapour, 159
exert, apply, give use to, 75
expand, increase in size, swell, 5
expire, breathe out, 18
expose, bring to view, uncover, 15
extent, length, etc., to which a thing extends, large space, 17
extract (v.), take out by force ; (n.) concentrated substance left after evaporation, etc., 36
eyebrow, curved strip of hair above eye, 95
fibre, *fibrous*, thread, threadlike, 71
file (v.), scrape with roughened steel tool (n.) ; (n.) *filings*, particles, scraped off by file, 9, 161

filter, apparatus for freeing a liquid from solid particles held by it ; *filtrate*, the liquid after separation of the solid particles from it, 39
finally, as the last result or act, 5
fluid, something that flows freely ; not a solid, 145
forceps, tool for seizing or holding objects, 73
formula, rule or fact expressed by signs and figures, 37
fraction, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc., 7, 163
fuel, material for fires (coal, wood), 6
funnel, Y-shaped vessel for pouring fluid into a small opening, 33
furrow, long narrow hole as made by plough, 122
fuse, melt by great heat, 11

germinate, begin to grow from seed, cause to shoot, 69
glue, sticky substance used for joining articles together, 81
graduated, marked according to a scale (cubic centimetres, etc.), 134
goldsmith, man who makes articles of gold, 144
graph, diagram showing relation between two sets of quantities, 125

hence, as a result of this ; therefore, 6

i.e. (L. *id est*), that is to say.
inorganic, of minerals: not *organic*, 99
interval, time or space between one event or object and another, 92
invert, turn upside down, 4
invisible, that cannot be seen, 6
involved, made necessary ; included, 124

jar, a deep vessel (see Fig. 98), 161
jet, stream of water, steam, gas, etc., shot through a small opening; the small end-piece of a tube through which a jet comes, 113, 157
jungle, thick tropical forest, 88
justify, give a good reason for, 171

label (*n.*), piece of paper fastened to an object giving its name or other particulars ; (*v.*) fasten a label to, 42, 156
laboratory, science workroom, 13
layer, thickness of matter, especially one of several, spread over a surface, 10
lens, glass giving a larger or smaller view of an object, 33
link, one ring of a chain, 170
loop (see Fig. 2), 2
lubricate, make smooth or slippery with oil, etc., 106
luminous, bright ; full of light, 13, 157
lungs, the two air-bags in the chest, used in breathing, 18

margin, extra amount over and above what is necessary, 150
maximum, greatest possible quantity or size, 104
mineral (*adj.* and *n.*), (substance) obtained from the earth, 65

minus, the sign — for taking away a quantity, 55
mirror, polished or glass surface that reflects light ; looking-glass, 162
mould, hollow pattern of wood or clay into which melted metal, etc., is poured for shaping, 24 ; a woolly growth which appears after a time on food, etc., left in the air, 18
mow, cut down (grass), 95

neutral, neither *acid* nor *alkaline*, 51
neutralize, make neutral, 51
normal, usual, regular, ordinary, 150

occupy, take up, fill, 1
organic, having organs, to do with plants or animals ; not mineral, 103
overlap, partly cover ; cover and extend beyond, 94

palm, inner surface of hand between wrist and fingers, 122
pan, shallow vessel, 162
parallel, continuously the same distance apart, 71
particle, very small bit of matter, 15
patch, piece of ground ; also piece of cloth, etc., put on to mend hole, 18
physical, belonging to physics as opposed to chemistry, 24
physics, science that deals with qualities of matter and energy, 24
plastics, produced by moulding, able to be moulded easily, 24
plus, the sign + for adding a quantity, 130
porcelain, very fine clay (pottery), 28, 159
pore, *porous*, very small opening (as in skin) through which fluids may pass, 99
precaution, care taken to avoid harm or gain success, 125
prick, make tiny hole, hurt with a sharp point, 122
principle, law of science, rule, 24
process, course of action, method of manufacture, 25
proportion, comparative relation between two things in size, etc. ; comparative part, 15
pungent, with stinging smell or taste, 50

ratio, comparison between two numbers or quantities. Thus 30 and 5 are in the ratio of 6 to 1, 143
razor, very sharp knife for taking hair off face, etc., 154
react, call out chemical activity, 30
reagent, substance used to discover presence of another substance by *reaction*, 42
refrigerator, apparatus for making and keeping food cool, 72
register, record, 150
relative (*adj.*), comparative, 40
residue, substance that remains after burning, etc., 34
reverse (*v.*), turn the other way round ; (*adj.*) opposite, 24
revolve, turn round and round ; roll (*intr.*), 132
rigid, stiff, 23
rudder, movable flat piece at the back of a boat or ship by which it is steered, 150

scramble, crawl and climb anyhow, 90
section, cutting; *cross-section*, area uncovered by cutting straight through an object, 23
seedling, tiny plant growing from seed, 67
senses, powers of hearing, sight, smell, etc., 6
series, set of similar or related things, 102
sewage, *drainage* of body wastes, 103
sieve, deep frame with cross wires stretched across bottom for separating smaller from larger particles by shaking them through the holes, 35
significant, having a meaning, of enough importance, 124, 171
sink, water basin in bench in laboratory, 156
slice, thin broad piece (of bread, meat) cut off, 75
soluble, able to dissolve, 39
solution, liquid or mixture formed by dissolving; being dissolved, 28
solvent, substance, usually a liquid, which can dissolve other substances, 38
spark, particle of fire, 50
sparkling, shining and flashing, 99
sphere, ball-shaped solid, 128
spiral, winding about in the shape of a *coil*; also *n.*, 25
splinter, sharp-edged thin piece of wood for lighting, 8
subtract, take away from, 130
suffocate, die through not being able to breathe, 45
summarize, make a short account of, 34
survive, continue to live, 94
suspended, *in suspension*, floating freely under the surface of a liquid, 38
synthesize, put together, cause elements to combine (opp. *analyse*), 46

tank, large container for liquid or gas, 150
temperate, neither very warm nor very cold, 150
thermometer, instrument for measuring temperature, 7
thread (of screw), *spiral* part of screw, 131
transplant, replant in a new place, 80
triangle, three-sided flat figure, 13, 159
twine, *coil* or wind round or about something, 89
typical, according to type or kind, 63

uniform, always the same, same throughout, not changing in form or character, not *varying*, 38

vary, change, make different, become different in degree or quality, 15
vegetative, formed of plants, 93
vertical, upright, at right angles to the earth's surface, 125
vigour, active strength or force, 38

washer, flat ring of leather, metal or rubber, 127
weld, cause (pieces of metal) to unite by heating, etc., 54
wilt (of plants), become soft, lose *vigour*, 82
winnow, separate light particles of plant from grain by blowing, 36

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